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Assessment of Northern Shrimp stocks in the Estuary and Gulf of St. Lawrence in 2013: data from the research survey

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TABLE OF CONTENTS

ABSTRACT IV
RÉSUMÉ IV
INTRODUCTION 1
DESCRIPTION OF THE SURVEY 1
PROCESSING OF SHRIMP CATCHES 1
DISTRIBUTION AND MEAN CATCH OF NORTHERN SHRIMP 2
BIOMASS ESTIMATION BY GEOSTATISTICS 2
ABUNDANCE ESTIMATION 3
ACKNOWLEDGEMENTS 4
REFERENCES 4
TABLES 5
FIGURES 20

ABSTRACT

The Estuary and Gulf of St. Lawrence Northern Shrimp (*Pandalus borealis*) stock status is determined every year by examining a main indicator from the commercial fishery and the research survey. This document presents the data and methods that were used to produce the 2013 survey indicators. The estimates of Northern Shrimp biomass and abundance are presented for each of the four fishing areas and for each sex.

RÉSUMÉ

L'état des stocks de crevette nordique (*Pandalus borealis*) de l'estuaire et du golfe du Saint-Laurent est déterminé chaque année par l'examen d'un indicateur principal provenant de la pêche commerciale et du relevé de recherche. Ce document présente les données et méthodes utilisées pour produire les indicateurs du relevé de 2013. Les estimations de biomasse et d'abondance de la crevette nordique sont présentées pour chacune des quatre zones de pêche et pour chacun des sexes.

INTRODUCTION

The Northern Shrimp (*Pandalus borealis*) fishery is conducted by trawlers in four shrimp fishing areas (SFA): Estuary (SFA 12), Sept-Iles (SFA 10), Anticosti (SFA 9) and Esquiman (SFA 8) (Figure 1). Fishing is regulated by several management measures, including the setting of total allowable catches (TAC) for each of the four areas. The TAC is set each year from the main stock status indicator. The main indicator of stock status is calculated from the male (recruitment to the female component) and female indices (spawning stock) obtained from the summer fishery (number per unit effort) and research survey (abundance) (DFO 2012, Savard 2012).

This document updates the data and methods that are used to produce the survey indicators and that were described in Savard and Bourdages 2013. The estimates of Northern Shrimp biomass and of abundance are presented for each of the four fishing areas and for each sex. The weight-length relationships are also presented as well as the length frequency distributions that are used for the age group identification.

DESCRIPTION OF THE SURVEY

A research survey has been conducted annually in the Estuary and the northern Gulf of St. Lawrence since 1990 to estimate the abundance of Northern Shrimp and of some groundfish species. The survey is conducted with a shrimp trawl following a stratified random sampling plan. Fishing operations take place 24 hours a day. A description of the 2013 survey and sampling protocols is presented in Archambault et al. 2014.

The stratification used for the allocation of fishing stations is presented in figure 2. In the Gulf, the grounds located at depths greater than 37 m (20 fathoms) are covered by the survey. In the Estuary, the survey covered the grounds at depths greater than 183 m (100 fathoms) from 1990 to 2007. In 2008, it was decided to add strata to cover depths from 37 to 183 m to obtain a better coverage of the Northern Shrimp spatial distribution. The surface of the study area has increased from 112,525 km2 to 114,950 km2.

In 2013, due to various problems, the mission time allocated to sampling has been greatly reduced so that the area of the Strait of Belle Isle was not sampled. In addition, the sampling effort was reduced on the west coast of Newfoundland (strata 835 and 836) and in the central Gulf (strata 803, 808, 811, 815 and 822). A total of 165 fishing stations were carried out with a 92% of success (152 tows, Figure 3) of the 199 who had previously been planned. On average, 190 fishing stations are sampled per year (Table 2).

PROCESSING OF SHRIMP CATCHES

For each fishing tow, the trawl catch is sorted by species or by taxon. The total catch of shrimp is weighted and a sample of about 2 kg is collected to determine the proportion of *Pandalus borealis* and its biological characteristics as well. The maturity stage (male, primiparous or mutiparous female with or without gonads in maturation and egg bearing female) is identified for each individual. The cephalothorax length is measured with an electronic calliper with a precision of 0.1 mm. The individual weight is recorded with a precision of 0.1 g following a stratified sampling design (about ten individuals per sex per 1 mm length class) for each fishing area.

The area swept by the trawl is estimated from the duration of the tow, the speed of the vessel and the wingspread of the trawl. The *P. borealis* catch for each tow is estimated from its proportion in the sample and is standardized to an area of 1 km² by dividing it by the swept area.

DISTRIBUTION AND MEAN CATCH OF NORTHERN SHRIMP

The survey is considered to cover well the whole *P. borealis* distribution in the Estuary and the northern Gulf of St. Lawrence (Figure 4). Northern Shrimp is generally restricted to grounds located under the cold intermediate layer at depths greater than 150 m.

The box plot of the catches is presented in figure 5. The mean catches are also presented by fishing area and by year, for males and females (Table 3a to 3d).

BIOMASS ESTIMATION BY GEOSTATISTICS

The biomass (kg/km²) calculated at all stations of the study area is kriged separately for males and females. First, the positions of sampling stations, expressed in latitude and longitude, are transformed into a Cartesian coordinate system according to the Lambert Conformal Conic projection using parallels 48^0N and 50^0N as a reference and 46.5^0N and 70^0O as point of origin. This conversion is carried out using libraries "sp" and "rgdal" (2013a Pebesma, Bivand 2013) of R (R Development Core Team 2008).

As a first step, a variogram is calculated for each survey. To highlight the spatial structure of the data, it is sometimes necessary to remove outliers. The values of cuts are shown in the table below (Table 1). Likewise, values lower than 5 kg/km^2 are not used for estimating the variogram. From 1990 to 2012, annual variograms were estimated with the procedure "VARIO" of SAS software (SAS 1996). In 2013, the variograms were performed with the library "gstat" of R (Pebesma 2013b). The semivariances were calculated between all pairs of stations. The distance (h) between them was discrete and semivariances were averaged for different distance classes with intervals of 15 km and a maximum distance of 225 km.

Table 1. Catch values above which the data were removed from the variogram estimation.

	2011	2012	2013
Male	3 000	8 000	-
Female	5 000	3 500	3 000
Total	7 000	10 500	-

In a second step, the annual variogram is standardized, that is to say that semivariances are divided by the observed variance of the data used to construct the variogram. Subsequently, a pluriannual variogram is constructed from the average of the last three variograms, that of the current year and the two preceding years. The pluriannual variogram corresponds to the mean of the semivariances for each distance h of the annual variograms, weighted by the number of pairs associated with these distances. The use of a pluriannual variogram reduces the variability of the spatial structure which is observed in some years, allowing a better fit of the model.

From 1990 to 2012, the parameters of pluriannual variograms (nugget, sill and range) were fitted manually to obtain the best possible adjustment (Tables 4a, 4b, 4c and Figure 6). Although other variogram models were examined but the exponential model was selected because it produced the best fit. In 2013, the parameters of the exponential variogram were fitted with the function "fit.variogram" from the library "gstat" of R (Pebesma 2013a). To minimize the least squares, the adjustment was performed by weighting the data by Nj/hj2 order to give more weight to the adjustment of the first points of the variogram.

Thereafter, the values of catches were spatially interpolated in the study area using kriging. To do this, all survey observations were used including low and extreme values. The pluriannual variogram was adjusted to represent the variance of the observations of the study area. The nugget (C0) and sill parameters (C) were multiplied by the variance of

all observations in the study area. The interpolation was performed on a regular grid with nodes separated by distances of 5 km in both directions (Figure 7). The local estimations were made using the catches of the eight nearest stations that are present within a maximum search radius of 200 km.

From 1990 to 2012, the kriging, the estimates of the mean and variance estimation were performed using the toolbox "Kriging" of MATLAB (Lafleur and Gratton 1998). In 2013, the kriging was performed with the function "krige" of the library "gstat" of R (Pebesma 2013a) and the estimates of the kriging mean and variance estimation were calculated using a function developed by Sébastien Durand (pers. comm.[1]).

The mean biomass (kg/km²) of each fishing area is then calculated by doing the mean of the local estimations in the area. The total biomass of a given fishing area is obtained by multiplying the mean biomass by the surface of the area. The surfaces of the fishing areas are as followed: Estuary, 4,000 km² from 1990 to 2007 and 6,325 km² from 2008 to 2013; Sept-Iles, 29,775 km² from 1990 to 2007 and 29,975 km² from 2008 to 2013; Anticosti, 46,400 km²; Esquiman, 32,350 km².

The mean biomass and the variance estimation are presented for males and females and, for each fishing area, in tables 5 and 6. In general, the coefficient of variation is about 20 to 25% for males and 10 to 20% for females for the fishing areas Sept-Iles, Anticosti and Esquiman (Table 7). The coefficient of variation id higher in the Estuary area. The distribution of the total biomass is presented by year (Figure 8) and for males and females (Figures 9 and 10). The total biomass for each fishing area, for males and females, is presented in table 8 and figure 11, as the total biomass in figure 12.

ABUNDANCE ESTIMATION

Biomasses estimated by kriging are converted into abundance from the weight-length relationships and from the length frequency distributions. Length frequencies of each sample are first bumped to the total catch of the station and then, standardized to a 1 km² swept area. The frequencies (n/km²) are regrouped into 0.5 mm size class.

The mean distribution of frequencies (in n/km²) per size class is estimated for each fishing area, for males and females. The mean distribution is estimated from all stations that were sampled in the fishing area. The mean distribution is then converted into weight by applying a weight-length relationship that is estimated for each area (Table 9, Figure 13). The weight-length relationship estimated in 1993 is used for the 1990-2004 period. Since 2005, the relationship estimated annually is used for the current year. The same relationship is used for both sexes.

The stock biomass estimated by kriging is distributed among the size classes following the proportions in weight of the mean distribution of the stock. The abundance of each size class is obtained by dividing the biomass by the mean weight of the class. The total stock abundance is then obtained by adding the abundance of all size classes. The exercise is done separately for males and females. Given that the numbers are not kriged, it is not possible to obtain an estimate of the variance of the abundance by kriging. Therefore, the coefficient of variation of the biomass is used to estimate the confidence interval of the abundance.

The total abundance of each fishing area is presented separately for males and females in table 10 and in figure 14. The abundance distributions by size class are presented for each fishing area in figure 15.

[1] Fisheries and Oceans Canada, Ottawa, ON, Canada

It is possible to obtain an index of recruitment by estimating the abundance of juveniles for which the cephalothorax length is smaller than 12.5 mm. The individuals of these sizes are aged of about fifteen months (Daoud et al. 2010). The estimation of abundance of the juveniles is obtained by adding the abundance of the size classes that are included in the first mode (Table 11).

The female abundance could be separated into maturity stages for the years when the identification of the stage was done for each individual. The abundance of primiparous and multiparous females was calculated from 1990 to 2000 and then from 2009 to 2013 and is presented in table 11. Carapace length frequencies by maturity stage from 1990 to 2013 are presented in figure 16.

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TABLES

Table 2. Mean catch (kg/km²) and standard error by year, for males and females for the whole studied area (n: number of stations).

Year	n	Males		Females	
		Mean	Standard error	Mean	Standard error
1990	219	352.82	55.45	485.40	52.97
1991	250	265.82	50.53	412.06	50.09
1992	239	155.81	26.40	243.78	29.20
1993	214	203.54	32.87	184.91	22.54
1994	176	201.97	33.29	302.52	38.02
1995	182	339.35	47.62	408.28	44.58
1996	217	439.20	61.95	680.02	57.96
1997	185	602.86	92.43	715.33	82.08
1998	206	352.74	40.84	723.20	73.51
1999	224	472.82	64.43	659.18	62.95
2000	209	527.95	64.46	971.07	82.90
2001	183	572.65	100.28	631.87	67.30
2002	171	470.10	88.08	797.65	88.41
2003	164	1429.82	303.30	1339.34	135.13
2004	133	726.31	136.25	1177.82	144.64
2005	354	536.26	72.52	931.05	68.46
2006	192	477.51	73.83	942.67	111.71
2007	183	610.36	101.27	1141.59	158.19
2008	189	489.42	84.41	762.88	82.69
2009	164	586.99	89.54	686.90	78.53
2010	154	484.47	70.62	750.55	88.77
2011	156	357.29	54.43	637.67	74.19
2012	178	506.20	114.22	533.69	75.38
2013	141	390.40	80.87	661.56	99.84
2008+	201	488.34	80.51	842.41	90.62
2009+	177	594.42	83.94	758.18	83.23
2010+	166	518.46	79.86	778.54	89.04
2011+	166	408.66	59.41	669.28	77.29
2012+	188	517.62	109.33	550.83	74.19
2013+	152	384.16	75.31	722.18	103.66

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 3a. Mean catch (kg/km²) and standard error by year, for males and females for the Estuary fishing area (n: number of stations).

Year	n	Males		Females	
		Mean	Standard error	Mean	Standard error
1990	12	156.25	77.65	233.61	82.82
1991	11	31.24	15.15	308.55	140.68
1992	11	83.54	64.96	187.46	120.92
1993	12	102.41	77.20	229.50	142.70
1994	8	119.91	83.71	398.97	271.60
1995	18	33.17	15.68	44.57	18.74
1996	17	134.76	53.69	663.28	244.99
1997	16	31.88	13.05	146.68	94.02
1998	16	34.28	18.47	161.68	64.15
1999	21	124.25	90.37	595.89	201.85
2000	17	54.87	20.71	440.12	129.51
2001	19	13.15	3.83	271.47	99.18
2002	12	10.37	6.37	125.36	81.22
2003	11	30.04	12.65	346.47	251.44
2004	9	140.28	109.56	722.38	367.21
2005	24	35.03	17.05	466.44	138.59
2006	12	5.88	2.02	208.70	76.78
2007	12	18.39	14.15	144.45	62.56
2008	10	17.15	6.47	379.29	159.29
2009	10	43.51	24.17	405.86	193.34
2010	12	77.14	42.62	240.66	137.05
2011	12	200.40	89.92	459.64	168.07
2012	11	168.99	104.58	541.06	296.08
2013	10	85.86	56.47	236.72	121.54
2008+	21	276.83	141.95	1377.73	446.43
2009+	23	407.83	121.58	1113.27	320.00
2010+	24	515.89	328.56	689.18	259.33
2011+	22	659.27	231.84	779.10	272.71
2012+	20	439.15	174.31	715.64	248.12
2013+	20	209.10	63.28	939.43	368.62

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 3b. Mean catch (kg/km²) and standard error by year, for males and females for the Sept-Iles fishing area (n: number of stations).

Year	n	Males		Females	
		Mean	Standard error	Mean	Standard error
1990	73	363.66	92.78	645.86	97.51
1991	71	556.17	162.63	828.80	150.54
1992	60	205.76	56.56	366.15	78.75
1993	47	376.53	94.10	378.57	73.66
1994	49	360.66	97.71	605.40	103.66
1995	56	466.30	96.10	576.97	95.30
1996	74	580.37	108.36	998.29	93.68
1997	53	827.35	159.76	1096.30	125.72
1998	48	533.44	86.71	1478.68	219.66
1999	62	715.15	119.52	989.22	102.19
2000	51	1011.01	164.56	1854.23	159.49
2001	58	1148.13	272.57	1132.31	155.61
2002	56	871.07	228.82	1693.13	194.24
2003	48	3127.78	919.28	2586.03	228.81
2004	43	1248.81	289.40	2115.14	274.29
2005	65	1216.63	286.98	1907.67	135.04
2006	50	655.37	157.80	1878.57	259.06
2007	50	1063.62	313.79	2293.54	339.10
2008	44	1015.41	288.14	2035.73	203.68
2009	44	823.43	240.35	1186.57	194.23
2010	40	644.76	150.85	1410.73	191.62
2011	40	416.78	86.94	1003.53	145.39
2012	42	1156.22	382.07	936.69	113.12
2013	41	548.73	212.81	995.85	251.10
2008+	45	993.14	282.54	1990.49	204.18
2009+	44	823.43	240.35	1186.57	194.23
2010+	40	644.76	150.85	1410.73	191.62
2011+	40	416.78	86.94	1003.53	145.39
2012+	43	1135.94	373.63	919.52	111.79
2013+	42	536.20	208.06	973.82	246.03

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 3c. Mean catch (kg/km²) and standard error by year, for males and females for the Anticosti fishing area (n: number of stations).

Year	n	Males		Females	
		Mean	Standard error	Mean	Standard error
1990	85	432.31	110.06	403.27	90.78
1991	82	185.46	37.18	257.11	41.09
1992	82	211.64	59.86	232.16	43.47
1993	76	207.97	64.32	141.47	25.94
1994	64	161.65	36.65	184.99	33.22
1995	57	378.61	87.89	470.25	71.13
1996	63	494.88	135.38	729.94	125.45
1997	60	489.24	105.34	608.32	86.48
1998	78	338.21	56.43	608.26	76.82
1999	78	381.33	67.30	566.39	68.19
2000	77	394.01	73.62	850.58	104.51
2001	36	203.38	60.44	373.76	59.71
2002	49	473.84	119.72	630.48	110.74
2003	46	802.28	297.96	852.30	205.04
2004	32	603.73	293.42	754.31	230.89
2005	134	515.13	96.85	972.22	112.60
2006	64	390.93	113.07	665.50	135.86
2007	66	581.38	106.72	1072.18	308.50
2008	66	287.94	59.28	392.16	72.02
2009	60	560.53	125.19	496.13	91.53
2010	54	522.60	121.99	564.85	114.99
2011	52	202.74	59.32	338.23	84.79
2012	59	190.57	45.90	338.13	62.69
2013	49	229.97	58.75	464.64	112.20

Table 3d. Mean catch (kg/km²) and standard error by year, for males and females for the Esquiman fishing area (n: number of stations).

Year	n	Males		Females	
		Mean	Standard error	Mean	Standard error
1990	49	246.89	73.44	450.48	94.34
1991	86	132.72	36.35	229.00	41.98
1992	86	76.95	20.47	176.71	38.87
1993	79	111.73	23.94	104.72	20.01
1994	55	119.45	37.17	155.42	36.81
1995	51	264.14	85.29	282.15	79.76
1996	63	299.84	100.71	260.78	58.81
1997	56	675.28	236.46	631.91	215.63
1998	64	314.53	87.65	437.06	104.71
1999	63	463.80	172.20	470.35	162.91
2000	64	429.80	124.03	553.29	164.08
2001	70	437.61	105.14	447.79	92.32
2002	54	153.06	68.92	170.08	53.91
2003	59	798.67	221.02	889.93	221.41
2004	49	455.49	171.87	715.51	219.18
2005	131	312.11	78.31	489.47	102.90
2006	66	512.48	138.68	635.87	191.06
2007	55	362.25	106.21	395.21	106.46
2008	69	415.18	116.38	361.40	100.03
2009	50	519.38	133.70	532.32	135.96
2010	48	409.84	126.00	536.80	167.72
2011	52	502.29	132.68	696.77	158.63
2012	66	430.91	171.38	450.81	170.26
2013	41	498.07	161.40	666.24	181.72

Table 4a. Parameters of the variograms used for kriging the male biomass. An exponential model was used each year.*

Year	Period	Parameters		
		Nugget (c_0)	Sill ($c_0 + c$)	Range (a_0)
1990	1990-1991-1992	0.50	1.05	35
1991	1990-1991-1992	0.50	1.05	35
1992	1990-1991-1992	0.50	1.05	35
1993	1991-1992-1993	0.20	1.05	30
1994	1992-1993-1994	0.20	1.05	30
1995	1993-1994-1995	0.20	1.00	20
1996	1994-1995-1996	0.20	1.00	20
1997	1995-1996-1997	0.20	0.95	18
1998	1996-1997-1998	0.20	0.90	20
1999	1997-1998-1999	0.40	0.90	20
2000	1998-1999-2000	0.40	0.90	20
2001	1999-2000-2001	0.40	0.90	17
2002	2000-2001-2002	0.30	1.00	25
2003	2001-2002-2003	0.20	1.00	25
2004	2002-2003-2004	0.20	1.00	25
2005	2003-2004-2005	0.30	1.00	30
2006	2004-2005-2006	0.30	1.00	25
2007	2005-2006-2007	0.30	1.00	25
2008	2006-2007-2008	0.30	1.00	20
2009	2007-2008-2009	0.25	1.00	25
2010	2008-2009-2010	0.30	1.00	25
2011	2009-2010-2011	0.40	1.00	30
2012	2010-2011-2012	0.30	1.00	22
2013	2011-2012-2013	0.00	0.96	15.67

* Exponential model : (where h = distance) $\gamma(h) = c_0 + c\left[1 - \exp\left(-\frac{h}{a_0}\right)\right]$

Table 4b. Parameters of the variograms used for kriging the female biomass. An exponential model was used each year.*

Year	Period	Parameters		
		Nugget (c_0)	Sill ($c_0 + c$)	Range (a_0)
1990	1990-1991-1992	0.45	0.95	30
1991	1990-1991-1992	0.45	0.95	30
1992	1990-1991-1992	0.45	0.95	30
1993	1991-1992-1993	0.25	0.85	20
1994	1992-1993-1994	0.30	0.85	25
1995	1993-1994-1995	0.30	0.80	20
1996	1994-1995-1996	0.15	0.95	17
1997	1995-1996-1997	0.15	0.95	17
1998	1996-1997-1998	0.20	0.95	20
1999	1997-1998-1999	0.35	0.90	25
2000	1998-1999-2000	0.35	0.90	30
2001	1999-2000-2001	0.40	0.90	35
2002	2000-2001-2002	0.30	0.90	30
2003	2001-2002-2003	0.20	0.85	35
2004	2002-2003-2004	0.15	0.95	35
2005	2003-2004-2005	0.20	1.05	60
2006	2004-2005-2006	0.20	1.05	50
2007	2005-2006-2007	0.20	1.05	60
2008	2006-2007-2008	0.20	1.00	60
2009	2007-2008-2009	0.20	0.90	40
2010	2008-2009-2010	0.25	0.90	45
2011	2009-2010-2011	0.15	0.90	28
2012	2010-2011-2012	0.15	0.90	27
2013	2011-2012-2013	0.60	1.52	441.11

* Exponential model : (where h = distance) $\gamma(h) = c_0 + c\left[1 - \exp\left(-\frac{h}{a_0}\right)\right]$

Table 4c. Parameters of the variograms used for kriging the total biomass. An exponential model was used each year.*

Year	Period	Parameters		
		Nugget (c_0)	Sill ($c_0 + c$)	Range (a_0)
1990	1990-1991-1992	0.40	1.00	35
1991	1990-1991-1992	0.40	1.00	35
1992	1990-1991-1992	0.40	1.00	35
1993	1991-1992-1993	0.30	0.95	40
1994	1992-1993-1994	0.30	0.95	32
1995	1993-1994-1995	0.30	0.95	25
1996	1994-1995-1996	0.20	1.05	20
1997	1995-1996-1997	0.20	1.00	20
1998	1996-1997-1998	0.20	1.00	25
1999	1997-1998-1999	0.30	0.90	25
2000	1998-1999-2000	0.35	0.90	30
2001	1999-2000-2001	0.50	1.00	80
2002	2000-2001-2002	0.45	1.00	70
2003	2001-2002-2003	0.40	1.00	70
2004	2002-2003-2004	0.20	1.00	40
2005	2003-2004-2005	0.25	1.05	60
2006	2004-2005-2006	0.30	1.05	60
2007	2005-2006-2007	0.30	1.05	60
2008	2006-2007-2008	0.30	1.05	55
2009	2007-2008-2009	0.30	1.05	55
2010	2008-2009-2010	0.35	1.00	40
2011	2009-2010-2011	0.25	1.00	30
2012	2010-2011-2012	0.20	0.95	20
2013	2011-2012-2013	0.00	0.87	11.49

* Exponential model : (where h = distance) $\gamma(h) = c_0 + c\left[1 - \exp\left(-\frac{h}{a_0}\right)\right]$

Table 5. Mean biomass (kg/km²) estimated by kriging, by fishing area and by year, for males (M) and females (F).

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	M	F	M	F	M	F	M	F
1990	188.6	310.4	388.1	648.7	416.8	417.3	234.2	402.2
1991	44.3	514.4	566.7	774.9	207.0	300.6	185.5	285.3
1992	100.1	365.0	219.6	358.7	264.7	276.9	92.4	202.5
1993	88.9	274.7	336.2	442.0	207.7	150.0	114.3	107.1
1994	102.6	426.1	376.1	598.4	165.3	179.5	175.6	196.0
1995	33.1	52.9	426.2	559.7	392.7	509.3	334.5	327.7
1996	116.6	598.7	467.0	880.3	659.8	931.3	329.5	299.2
1997	69.7	375.4	777.1	999.6	456.7	552.9	747.2	693.7
1998	28.5	159.8	551.5	1547.1	269.5	566.0	366.8	481.2
1999	136.2	575.2	788.0	1098.1	345.9	551.8	455.2	457.9
2000	141.1	702.3	1005.3	1777.0	403.7	832.1	439.2	536.7
2001	22.2	439.9	1273.0	1141.8	331.2	508.2	452.4	452.5
2002	22.0	312.8	980.1	1713.4	594.6	739.3	197.3	217.5
2003	105.8	691.4	2952.5	2767.2	966.3	1232.6	873.0	998.5
2004	92.5	626.6	1444.4	2312.4	564.3	905.2	434.7	767.7
2005	44.5	554.1	925.6	1978.1	655.3	1141.8	596.3	853.3
2006	45.8	419.7	631.4	1872.6	385.9	685.5	713.6	847.1
2007	221.4	592.0	945.0	2363.8	623.5	1223.2	517.6	462.7
2008	23.6	617.7	835.7	2112.6	361.7	481.1	492.9	426.4
2009	49.0	356.0	1031.0	1336.2	593.7	532.2	547.0	536.9
2010	98.7	341.0	715.6	1527.8	534.5	570.9	447.7	568.0
2011	185.9	496.6	488.8	1024.7	218.0	432.3	624.7	831.8
2012	160.7	658.3	1223.6	1015.0	268.4	473.3	452.8	507.7
2013	110.2	367.9	669.0	1037.5	236.1	508.9	435.1	659.9
2008+	284.6	1405.4	833.4	2103.8				
2009+	421.3	1157.2	1028.8	1334.6				
2010+	540.0	709.0	714.2	1526.1				
2011+	557.9	588.7	490.2	1014.4				
2012+	490.8	779.4	1220.6	1007.8				
2013+	226.7	795.7	666.2	1029.1				

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 6. Variance of the estimation of the kriged biomass, by fishing area and by year, for males (M) and females (F).

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	M	F	M	F	M	F	M	F
1990	4593.2	4833.7	8255.1	8469.6	10977.8	6917.7	4802.9	7276.9
1991	189.7	15113.8	22196.8	17747.4	1265.2	1435.8	1228.1	1518.9
1992	3381.0	10859.2	2757.4	4974.5	3326.8	1636.0	343.5	1145.1
1993	3482.4	12623.9	5228.9	3334.8	3117.6	496.8	366.9	266.8
1994	4251.7	44887.0	6501.8	7157.8	1106.0	856.2	1031.5	987.0
1995	135.0	190.8	6028.8	5479.6	6482.9	3642.4	6978.5	5122.2
1996	1723.6	35077.1	9531.7	6893.1	17463.4	14585.0	7607.8	2546.7
1997	90.9	4508.4	18806.9	11438.4	12013.4	8092.6	44216.3	36383.9
1998	218.4	1727.6	5002.7	33605.5	2811.2	5477.6	4864.0	7254.4
1999	6042.9	27055.7	13218.0	9064.4	4150.4	4018.7	24527.3	20394.0
2000	291.6	9848.0	21631.5	17930.6	4676.1	8495.9	11177.2	16974.2
2001	11.3	6581.7	58554.6	16209.3	3886.5	4714.9	8743.9	5870.2
2002	27.8	4020.6	36174.4	22907.2	13616.3	10273.6	4046.9	2161.7
2003	125.8	39123.2	671578.2	32616.6	77032.7	28571.9	41275.0	32368.2
2004	7523.5	65552.6	72131.7	50945.2	93148.3	55312.7	21248.1	27466.8
2005	206.7	8971.9	84840.6	13234.4	11480.1	11319.1	6845.0	8113.6
2006	2.8	2762.2	16011.5	29251.2	12704.6	14892.7	15129.8	20124.7
2007	186.3	2686.0	72079.6	54547.2	8341.3	45768.6	9289.7	6329.0
2008	33.2	12783.9	69789.5	21423.8	2993.8	2623.6	12119.6	5642.8
2009	372.3	17218.2	42898.4	21100.4	15001.2	6167.6	14323.4	10689.4
2010	1352.5	10110.3	17455.2	20606.3	13020.4	8385.8	11540.0	14445.9
2011	5748.1	14016.1	6343.1	14156.2	2979.9	4768.0	14628.7	16122.8
2012	9147.7	55185.7	110878.5	7273.6	2111.8	3311.3	24943.3	18554.0
2013	2024.2	10692.2	34932.8	46665.2	3018.9	9644.9	20206.9	24445.4
2008+	16391.8	102556.3	67827.6	21841.1				
2009+	8170.0	40838.5	42864.5	21071.4				
2010+	70573.5	31641.8	17443.8	20581.8				
2011+	39732.3	39000.7	6354.5	14200.4				
2012+	24374.1	36176.7	106421.6	7136.0				
2013+	2488.5	103621.7	33892.4	45328.1				

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 7. Coefficient of variation of the kriged biomass, by fishing area and by year, for males (M) and females (F).

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	M	F	M	F	M	F	M	F
1990	35.9	22.4	23.4	14.2	25.1	19.9	29.6	21.2
1991	31.1	23.9	26.3	17.2	17.2	12.6	18.9	13.7
1992	58.1	28.5	23.9	19.7	21.8	14.6	20.1	16.7
1993	66.4	40.9	21.5	13.1	26.9	14.9	16.8	15.2
1994	63.5	49.7	21.4	14.1	20.1	16.3	18.3	16.0
1995	35.1	26.1	18.2	13.2	20.5	11.9	25.0	21.8
1996	35.6	31.3	20.9	9.4	20.0	13.0	26.5	16.9
1997	13.7	17.9	17.6	10.7	24.0	16.3	28.1	27.5
1998	51.8	26.0	12.8	11.8	19.7	13.1	19.0	17.7
1999	57.1	28.6	14.6	8.7	18.6	11.5	34.4	31.2
2000	12.1	14.1	14.6	7.5	16.9	11.1	24.1	24.3
2001	15.1	18.4	19.0	11.2	18.8	13.5	20.7	16.9
2002	24.0	20.3	19.4	8.8	19.6	13.7	32.2	21.4
2003	10.6	28.6	27.8	6.5	28.7	13.7	23.3	18.0
2004	93.7	40.9	18.6	9.8	54.1	26.0	33.5	21.6
2005	32.3	17.1	31.5	5.8	16.4	9.3	13.9	10.6
2006	3.6	12.5	20.0	9.1	29.2	17.8	17.2	16.7
2007	6.2	8.8	28.4	9.9	14.6	17.5	18.6	17.2
2008	24.4	18.3	31.6	6.9	15.1	10.6	22.3	17.6
2009	39.4	36.9	20.1	10.9	20.6	14.8	21.9	19.3
2010	37.3	29.5	18.5	9.4	21.3	16.0	24.0	21.2
2011	40.8	23.8	16.3	11.6	25.0	16.0	19.4	15.3
2012	59.5	35.7	27.2	8.4	17.1	12.2	34.9	26.8
2013	40.8	28.1	27.9	20.8	23.3	19.3	32.7	23.7
2008+	45.0	22.8	31.2	7.0				
2009+	21.5	17.5	20.1	10.9				
2010+	49.2	25.1	18.5	9.4				
2011+	35.7	33.5	16.3	11.7				
2012+	31.8	24.4	26.7	8.4				
2013+	22.0	40.5	27.6	20.7				

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 8. Stock biomass (ton) estimated by kriging by fishing area and by year, for males (M) and females (F).

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	M	F	M	F	M	F	M	F
1990	755	1241	11557	19314	19339	19361	7577	13011
1991	177	2057	16874	23073	9606	13948	6000	9228
1992	400	1460	6538	10681	12284	12850	2989	6551
1993	356	1099	10011	13161	9636	6962	3698	3465
1994	410	1704	11198	17818	7670	8331	5681	6340
1995	133	212	12689	16667	18222	23630	10822	10602
1996	466	2395	13906	26212	30616	43214	10658	9680
1997	279	1501	23139	29763	21191	25653	24171	22443
1998	114	639	16421	46063	12503	26263	11867	15566
1999	545	2301	23464	32695	16051	25605	14724	14812
2000	564	2809	29934	52910	18732	38608	14207	17364
2001	89	1760	37905	33996	15366	23580	14635	14640
2002	88	1251	29184	51016	27590	34304	6382	7036
2003	423	2766	87909	82392	44836	57195	28242	32301
2004	370	2506	43008	68852	26182	42000	14062	24836
2005	178	2216	27558	58899	30406	52977	19292	27603
2006	183	1679	18800	55756	17905	31806	23086	27404
2007	885	2368	28137	70382	28931	56758	16745	14969
2008	94	2471	24883	62904	16781	22321	15944	13794
2009	196	1424	30697	39786	27549	24693	17697	17369
2010	395	1364	21308	45490	24802	26489	14483	18374
2011	744	1987	14555	30511	10115	20060	20209	26907
2012	643	2633	36433	30222	12456	21963	14648	16425
2013	441	1471	19919	30891	10956	23614	14077	21349
2008	1800	8889	24898	62852				
2009	2665	7319	30734	39873				
2010	3415	4484	21337	45591				
2011	3529	3724	14644	30305				
2012	3104	4930	36466	30108				
2013	1434	5033	19902	30745				

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 9. Parameters for the weight-length relationships by fishing area and by year. Length in mm and weight in g.*

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	a	b	a	b	a	b	a	b
1993	0.00071	2.945	0.00066	2.978	0.00059	3.018	0.00094	2.864
2005	0.001175	2.777	0.000654	2.960	0.000659	2.957	0.000754	2.904
2006	0.000682	2.945	0.000694	2.934	0.000527	3.040	0.000933	2.849
2007	0.001071	2.800	0.000724	2.930	0.000735	2.918	0.000767	2.904
2008	0.000561	3.016	0.000704	2.934	0.000769	2.908	0.000820	2.887
2009	0.000628	2.977	0.000897	2.864	0.000800	2.893	0.000767	2.911
2010	0.000759	2.920	0.000716	2.931	0.000585	3.011	0.000706	2.953
2011	0.000760	2.911	0.000685	2.942	0.000616	3.001	0.000544	3.036
2012	0.000733	2.931	0.000725	2.936	0.000771	2.923	0.000814	2.908
2013	0.000624	2.979	0.000643	2.976	0.000561	3.028	0.000672	2.967

* Model: Weight = a Length ^{b}

Table 10. Stock abundance (in million) by fishing area and by year, for males (M) and females (F).

Year	Estuary		Sept-Iles		Anticosti		Esquiman	
	M	F	M	F	M	F	M	F
1990	156	115	2258	1814	4849	2145	1661	1394
1991	26	196	3871	2278	1948	1458	1210	972
1992	87	128	2113	961	2928	1252	630	660
1993	85	92	2894	1264	2648	671	866	358
1994	87	163	3292	1918	1888	919	1471	716
1995	40	20	2920	1707	4854	2682	2681	1368
1996	86	226	3017	2667	7387	4769	3197	1207
1997	48	132	4939	2830	5852	2603	6497	2791
1998	29	54	3447	4212	2605	2563	3099	1808
1999	118	205	5797	3112	3910	2560	4112	1846
2000	114	257	6531	5329	4957	4008	4020	2137
2001	18	162	8559	3503	3604	2424	4610	1921
2002	20	125	6661	5543	7995	3898	1741	907
2003	219	271	17561	8982	12628	6741	8046	4298
2004	62	238	8521	7715	7070	5149	3740	3421
2005	29	222	6280	6498	6319	6441	4885	3913
2006	28	164	3806	6132	4322	3781	7165	3669
2007	141	226	6171	7251	8128	7224	5890	2243
2008	19	222	5613	6530	4809	2839	4938	2199
2009	43	133	7937	4311	9970	3258	5374	2529
2010	79	129	5942	5273	6481	3254	3634	2470
2011	178	231	3753	3639	2629	2421	5916	3404
2012	131	306	8345	3632	2961	2558	4310	2083
2013	143	158	4251	3513	2556	2787	3670	2741
2008+	456	831	5626	6525				
2009+	1253	732	7946	4321				
2010+	1073	467	5950	5284				
2011+	1070	433	3776	3614				
2012+	822	586	8355	3619				
2013+	455	611	4249	3497				

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

Table 11. Abundance (in million) for juveniles (J), primiparous (Fp) and mutiparous (Fm) females, by fishing area and by year.

Year	Estuary			Sept-Iles			Anticosti			Esquiman		
	J	Fp	Fm	J	Fp	Fm	J	Fp	Fm	J	Fp	Fm
1990	11	48	67	124	959	855	74	1535	610	4	1157	237
1991	0	57	138	349	773	1505	87	837	621	70	535	437
1992	0	43	85	342	556	404	394	843	408	50	554	106
1993	1	78	14	113	1031	234	29	580	92	23	234	124
1994	0	130	33	172	1600	318	19	802	118	98	627	90
1995	12	14	5	188	1496	211	493	2408	273	30	1182	185
1996	1	132	94	166	2011	656	1249	4048	721	637	881	327
1997	0	110	22	45	2294	535	609	2377	226	76	2063	728
1998	7	32	22	705	3498	714	204	2171	392	553	1567	241
1999	1	158	47	14	2707	405	26	2067	492	128	1284	563
2000	1	181	76	234	4544	785	688	3457	551	654	1612	525
2001	0			82			20			268		
2002	0			77			444			25		
2003	114			222			553			193		
2004	0			84			64			17		
2005	0			85			103			366		
2006	0			54			248			101		
2007	2			505			478			443		
2008	2			127			349			58		
2009	2	27	105	125	2022	2289	1258	2115	1144	127	1811	717
2010	0	60	69	64	3392	1880	83	1836	1418	146	1077	1393
2011	1	118	113	22	2058	1581	126	1709	712	533	2516	887
2012	2	258	48	203	2611	1022	35	1997	561	87	1591	492
2013	39	119	39	392	2735	779	138	2331	456	123	2331	410
2008+	136			136								
2009+	519	347	385	125	2026	2294						
2010+	17	321	146	64	3400	1884						
2011+	82	237	196	22	2044	1571						
2012+	78	442	144	206	2600	1019						
2013+	94	504	107	392	2722	775						

+: From 2008, the sampling was increased with the addition of strata in shallow waters (37 to 183 m) in the Estuary.

FIGURES

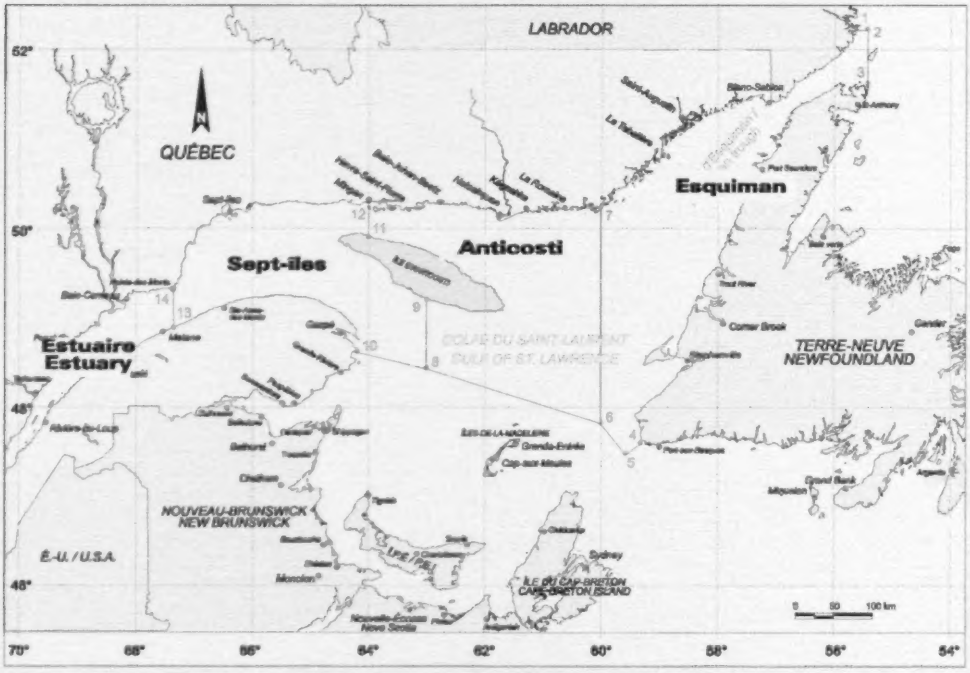

Figure 1. Shrimp fishing areas (SFA) in the northern Gulf of St. Lawrence: Estuary (SFA 12); Sept-Iles (SFA 10); Anticosti (SFA 9); Esquiman (SFA 8).

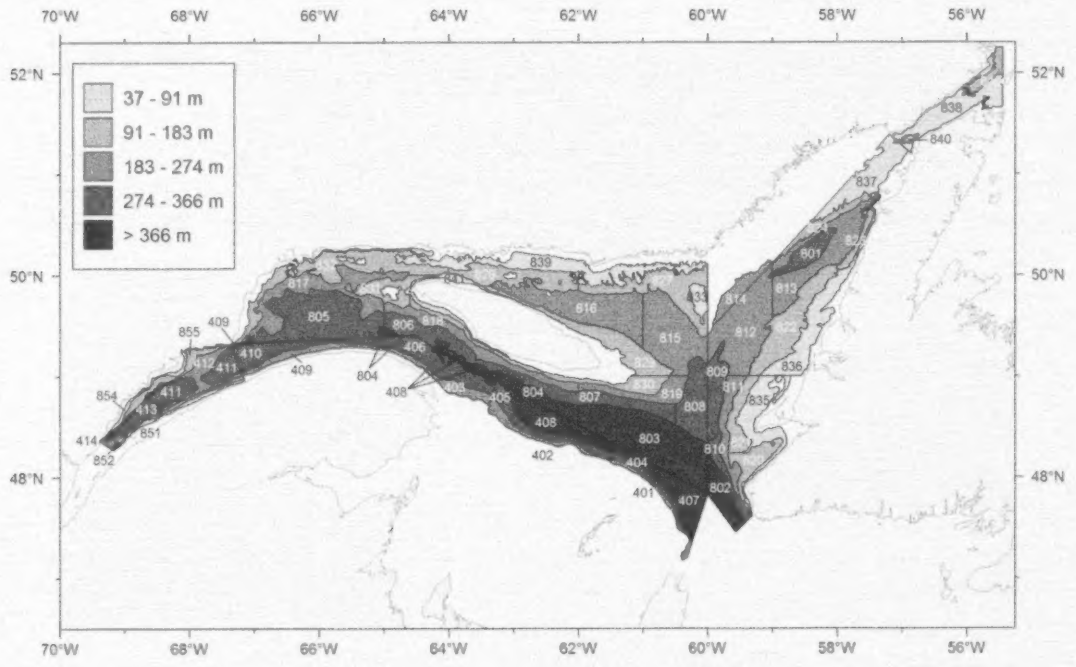

Figure 2. Stratification used for the allocation of fishing stations of the survey in the northern Gulf of St. Lawrence. The strata 851, 852, 854 and 855 were added in 2008.

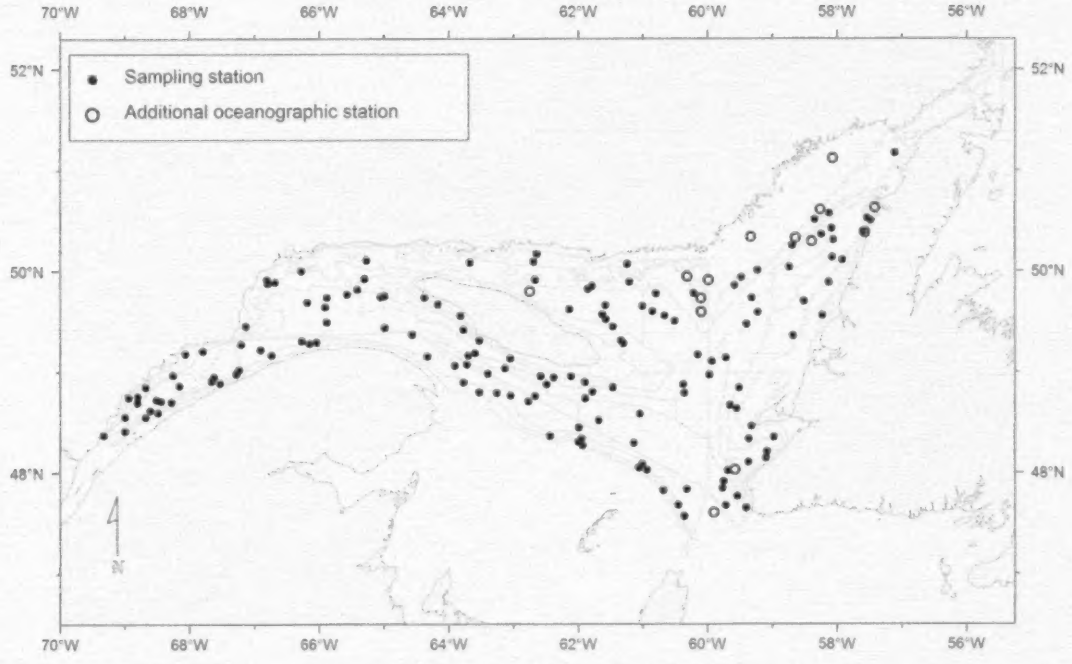

Figure 3. Locations of successful sampling stations (trawl and oceanography) and additional oceanographic stations for the 2013 survey.

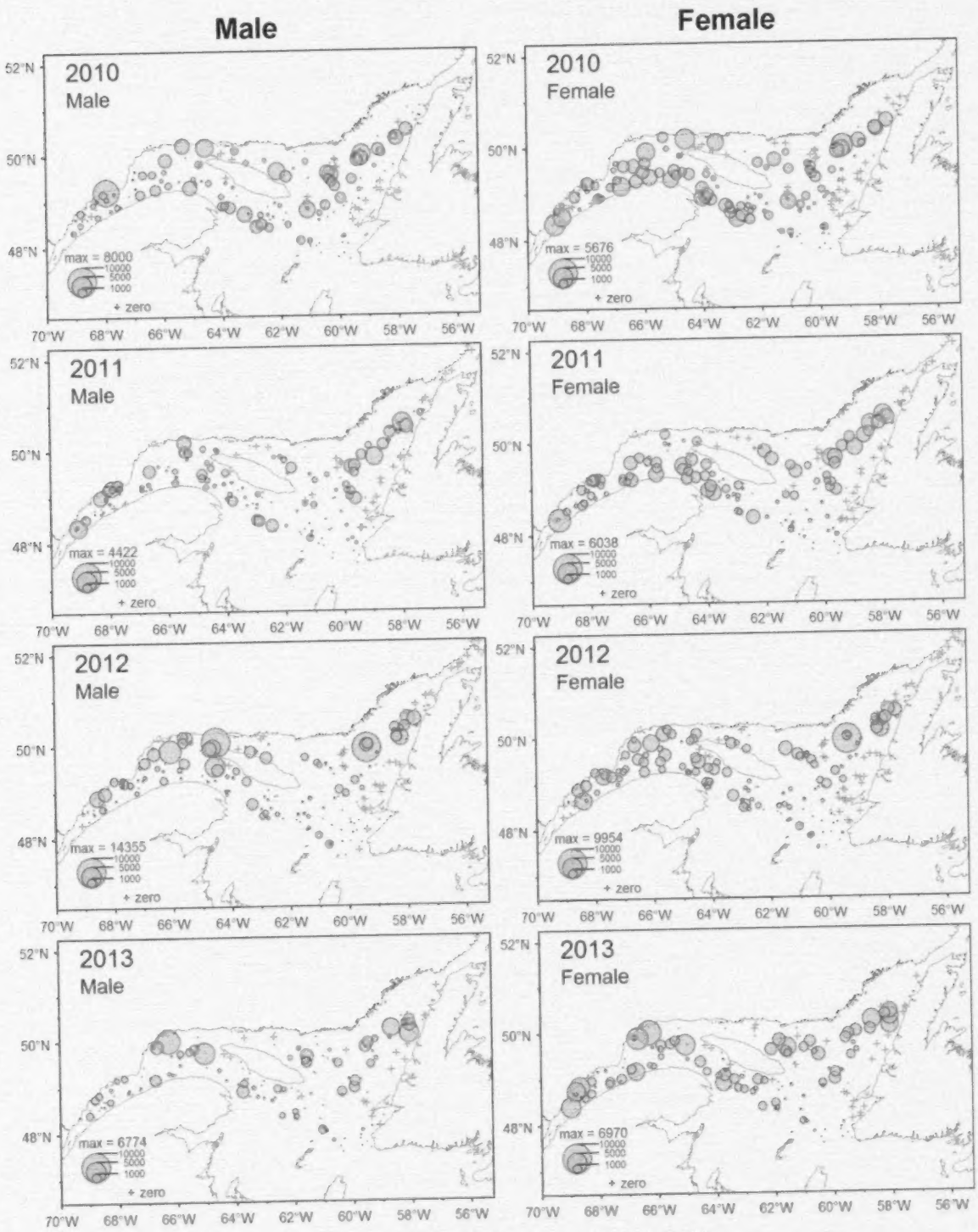

Figure 4. Distribution of male and female shrimp catches from 2010 to 2013.

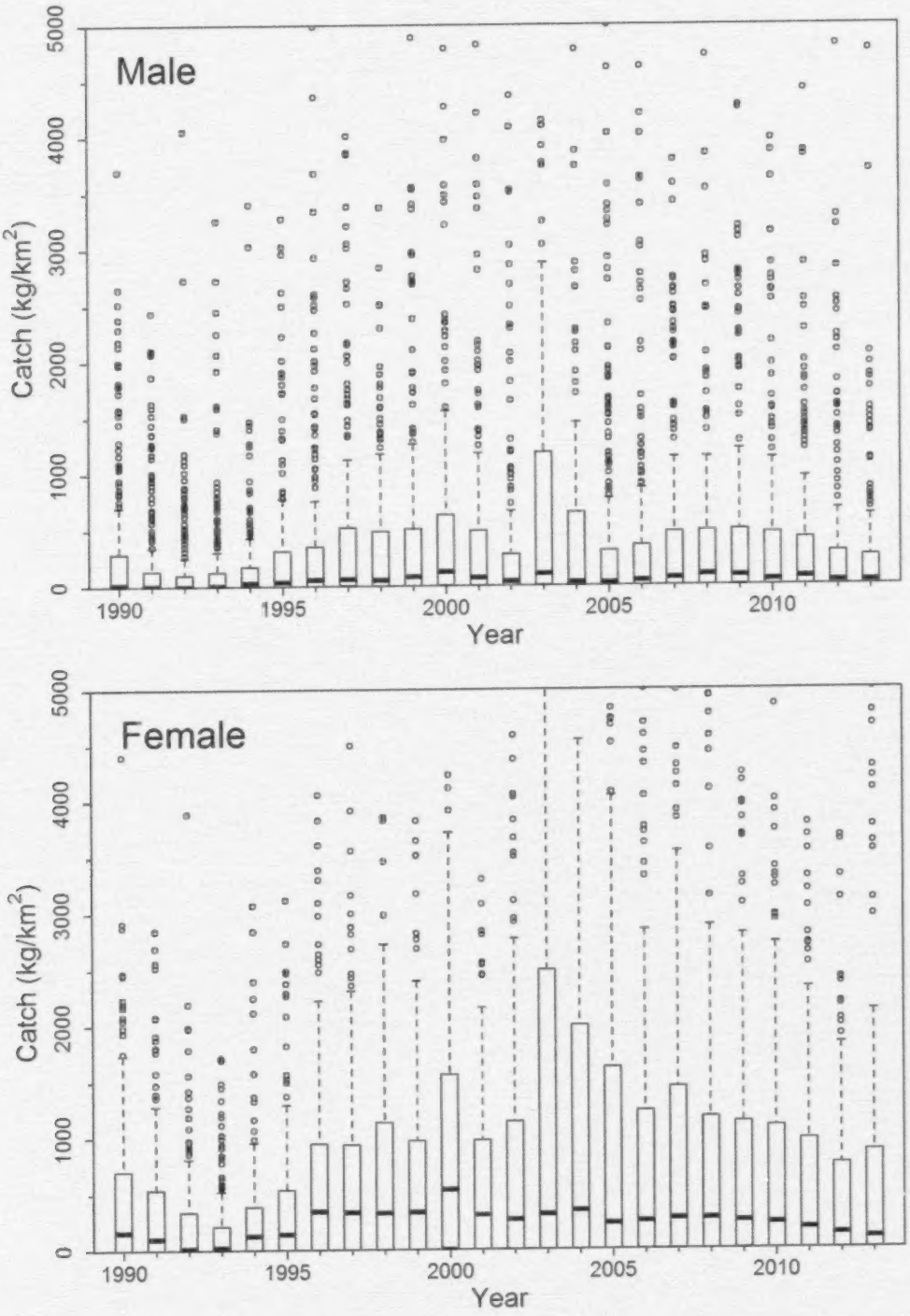

Figure 5. Boxplot of male and female shrimp catches (kg/km²) obtained from the surveys conducted from 1990 to 2013.

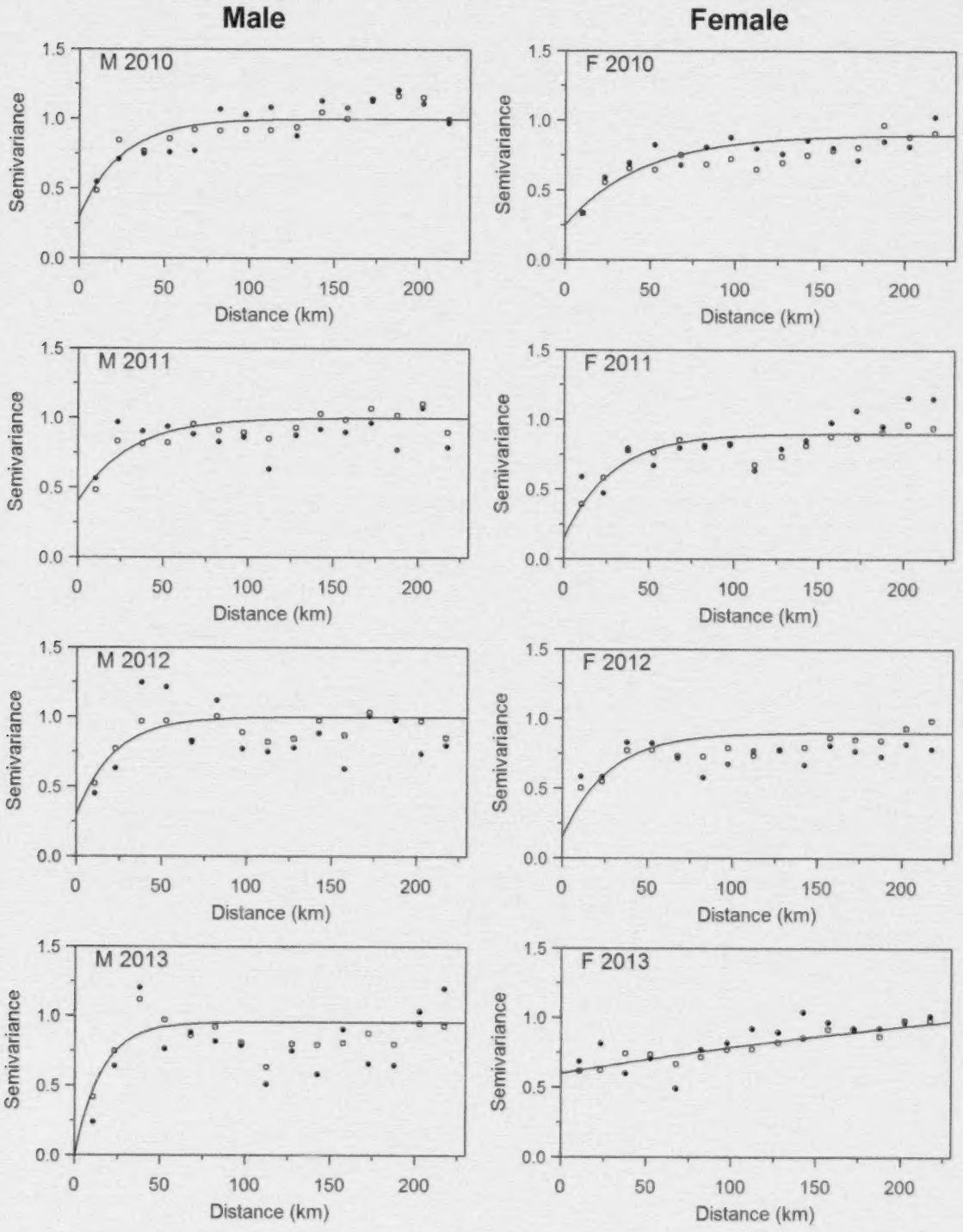

Figure 6. Isotropic variograms of the biomasses (kg/km²) for the years 2010 to 2013. Filled circles: current year. Open circles: mean over three years. Curve: variogram adjusted on the 3 year mean.

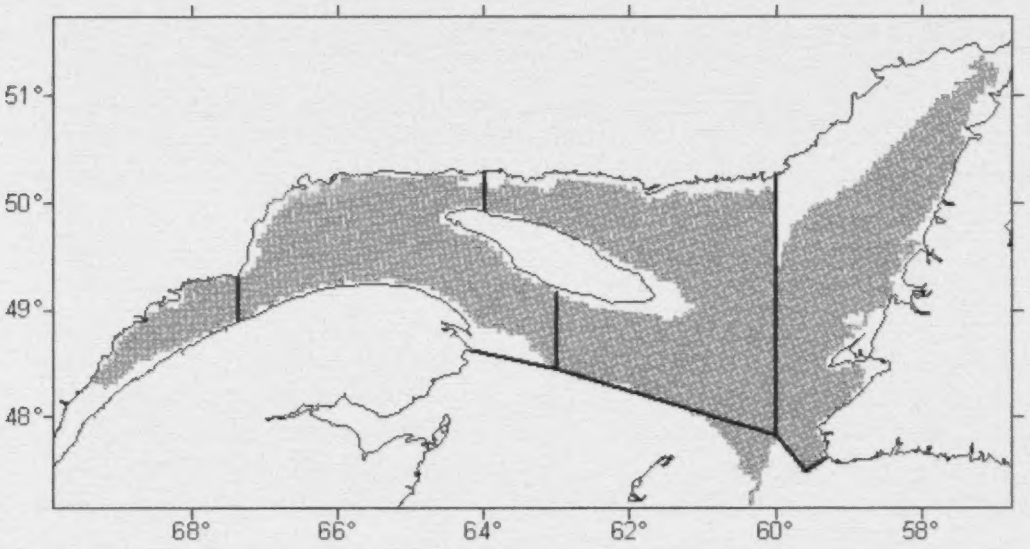

Figure 7. Studied area for the kriging of the shrimp biomass in the northern Gulf of St. Lawrence. The limits of the fishing areas are indicated as well.

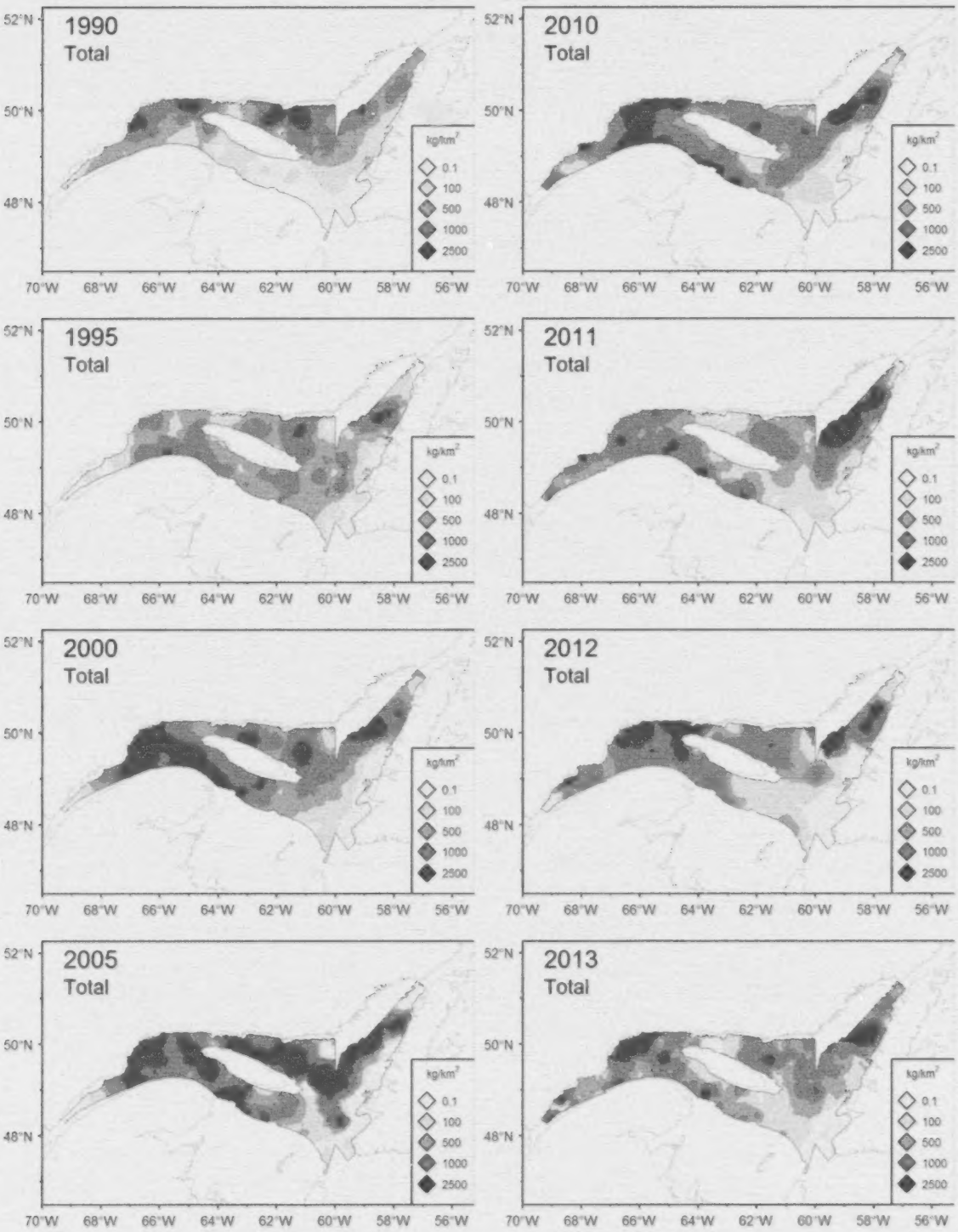

Figure 8. Distribution of the biomass (kg/km²) obtained by kriging for years 1990, 1995, 2000, 2005 and from 2010 to 2013.

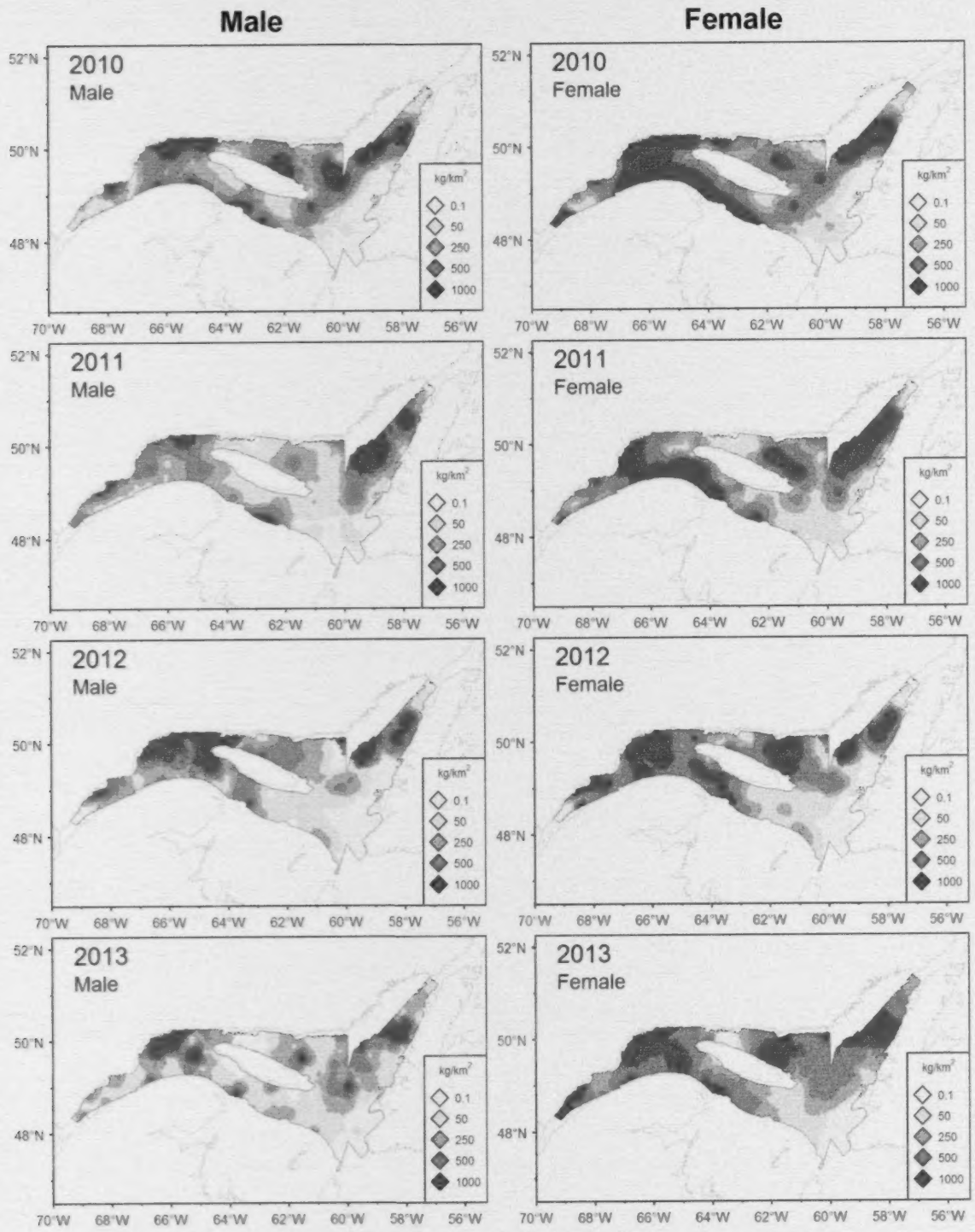

Figure 9. Distribution of the biomass (kg/km²) obtained by kriging from 2010 to 2013 for males and females.

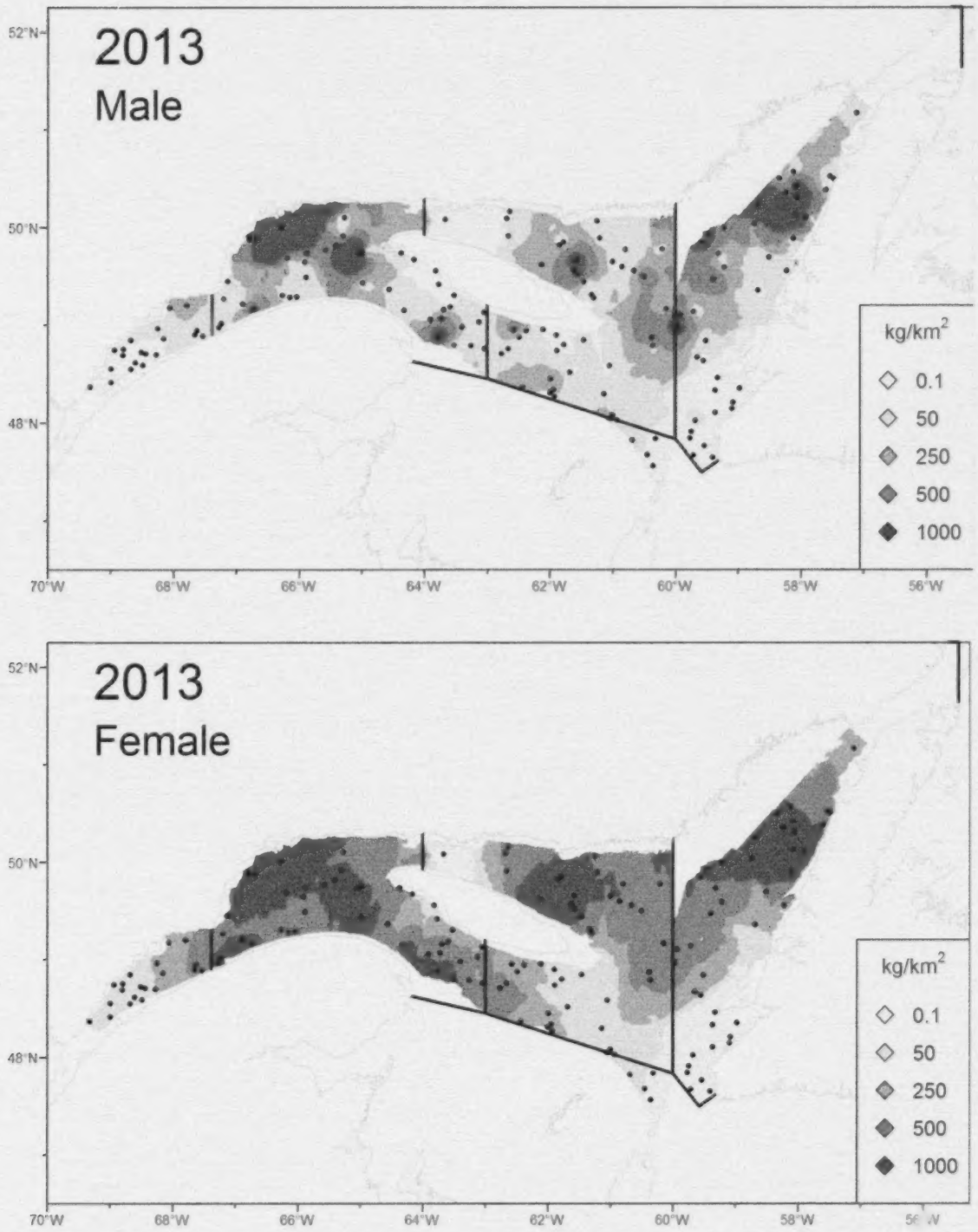

Figure 10. Distribution of the biomass (kg/km²) obtained by kriging in 2013 for males and females. The dots represent the sampled tows.

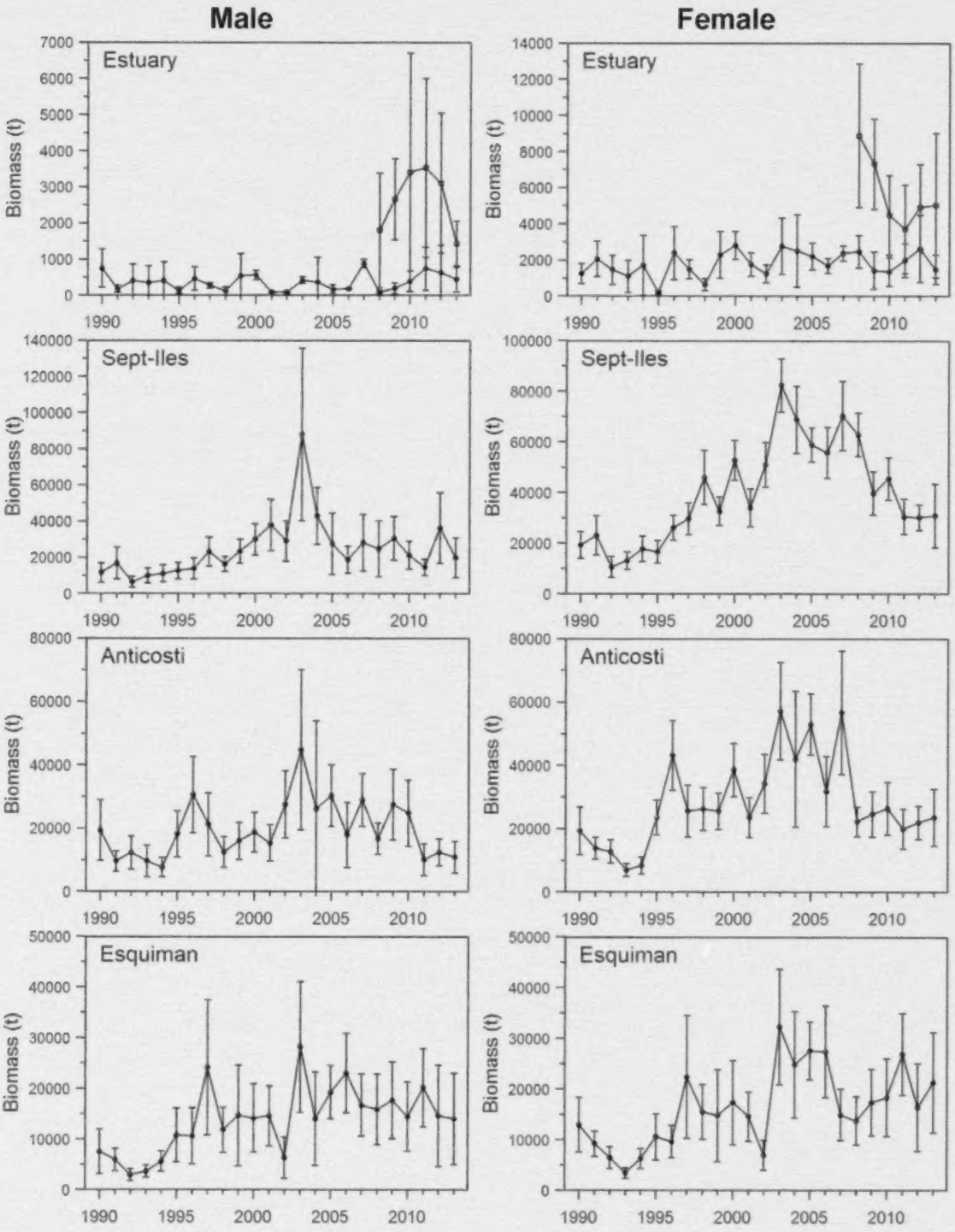

Figure 11. Biomass (in ton) by fishing area and by year, for males and females. The open circles from 2008 to 2013 show the results obtained when adding strata in shallow waters (37-183 m) of the estuary. Error bars indicate the 95% confidence interval.

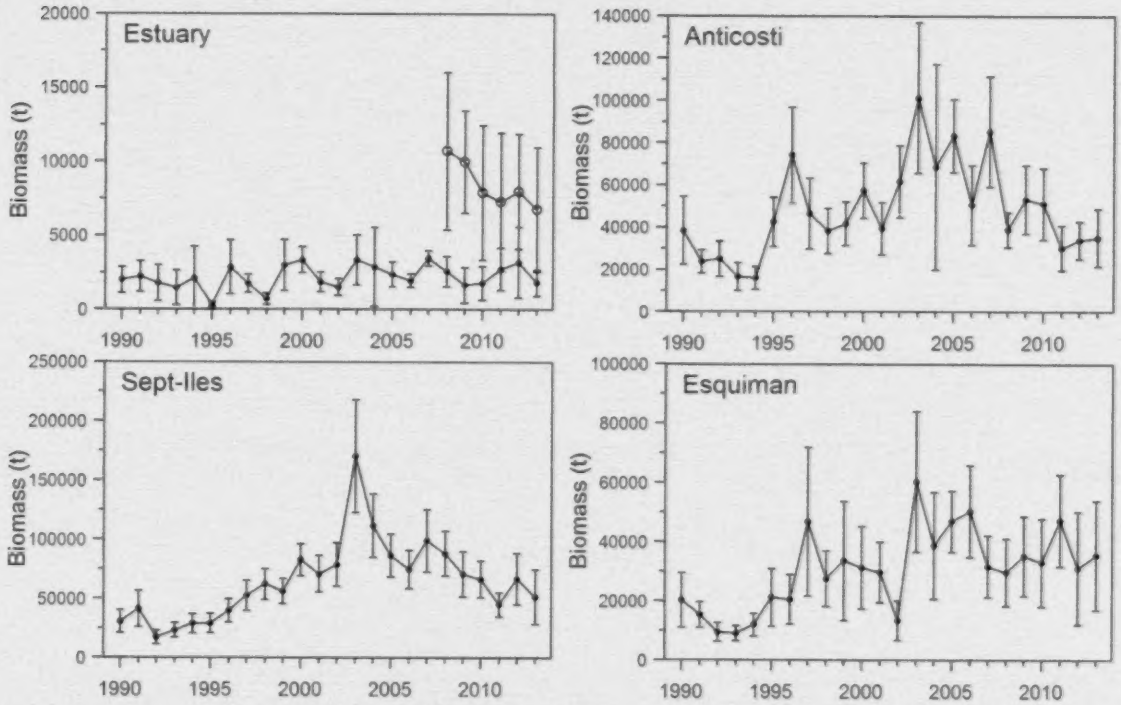

Figure 12. Biomass (in ton) by fishing area and by year. The open circles from 2008 to 2013 show the results obtained when adding strata in shallow waters (37-183 m) of the estuary. Error bars indicate the 95% confidence interval.

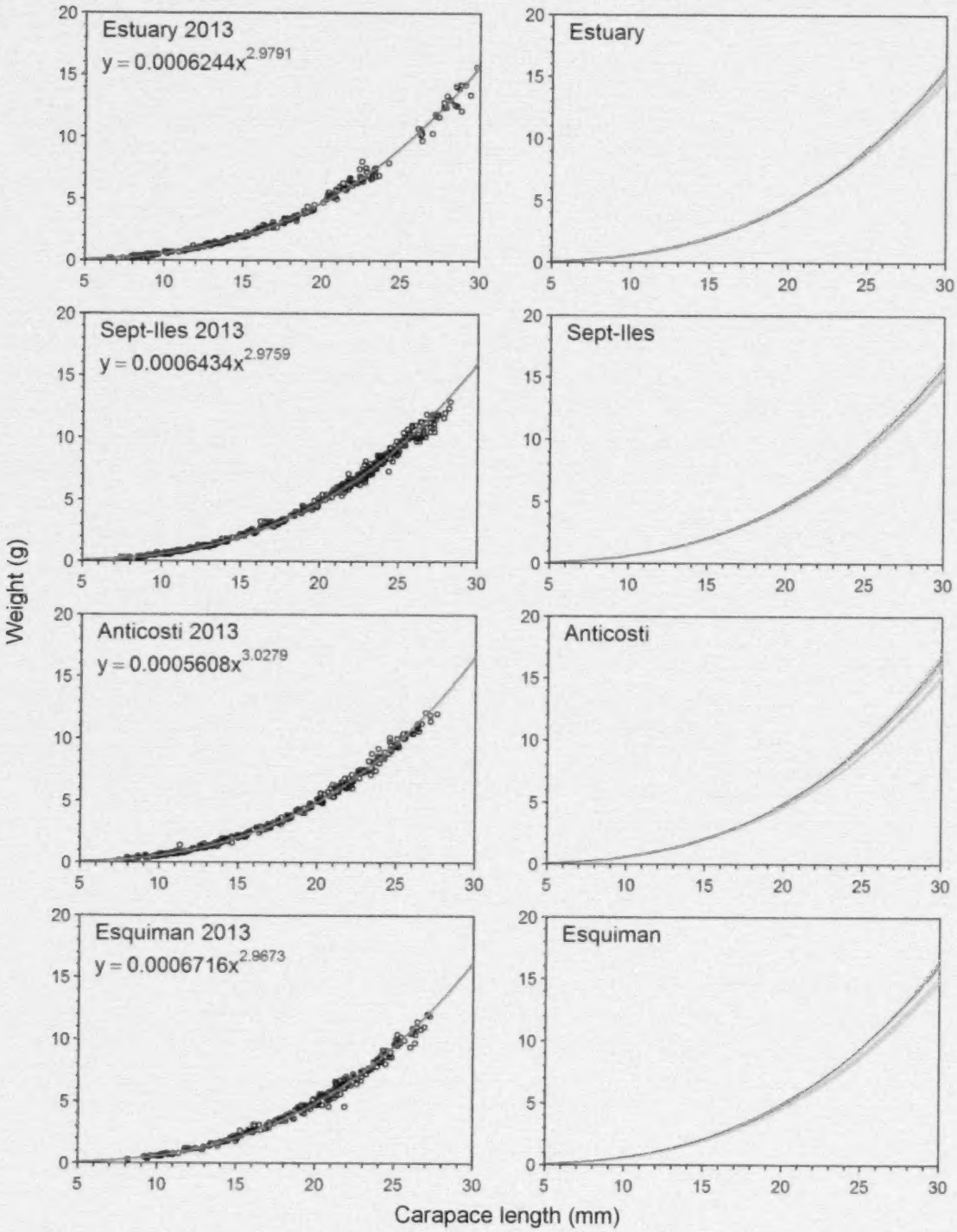

Figure 13. Weight-length relationships by fishing area. In the right panels, the red line represents the year 2013 and the gray lines 1993 and 2005 to 2012.

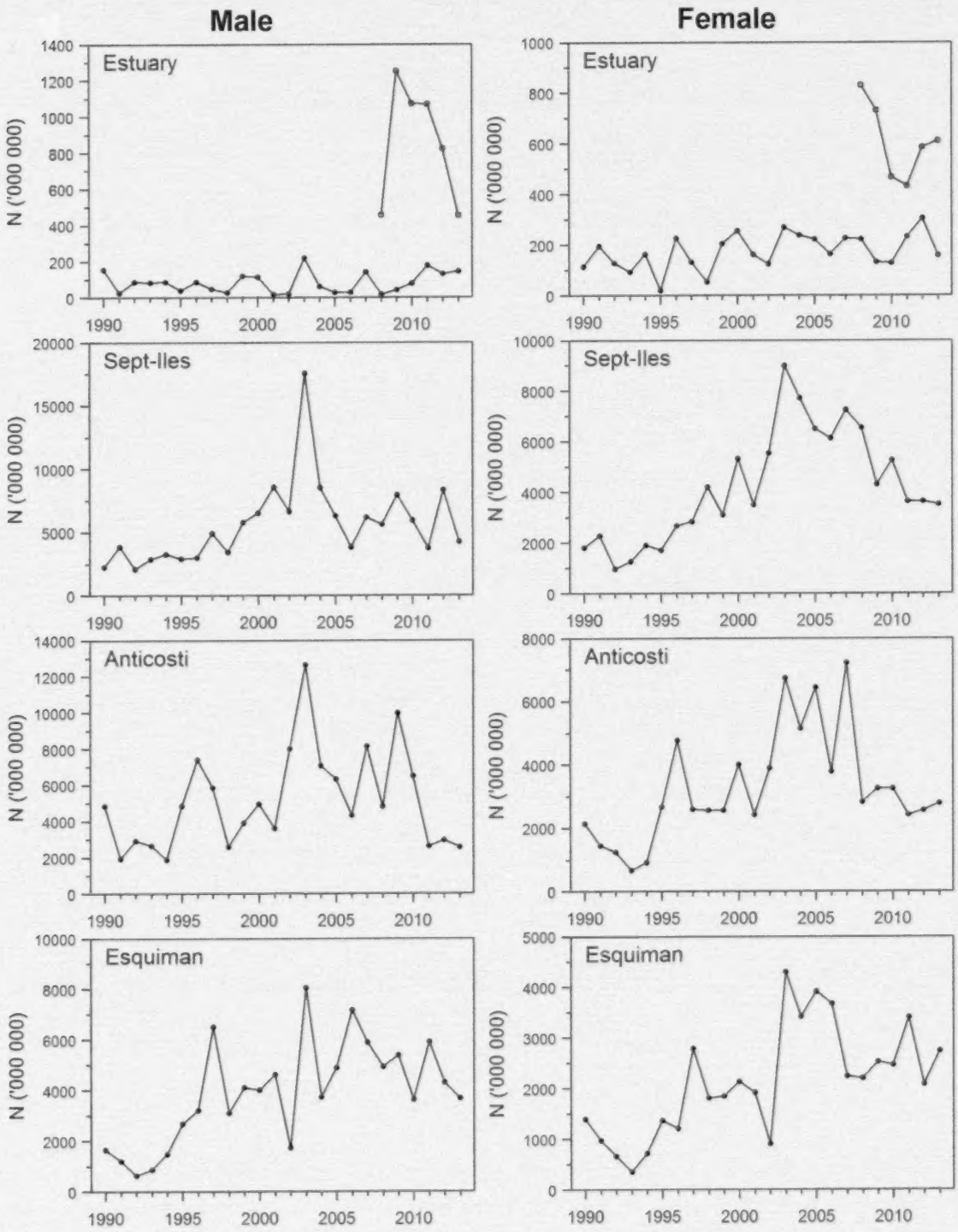

Figure 14. Abundance (in million) by fishing area and by year, for males and females. The open circles from 2008 to 2013 show the results obtained when adding strata in shallow waters (37-183 m) of the estuary.

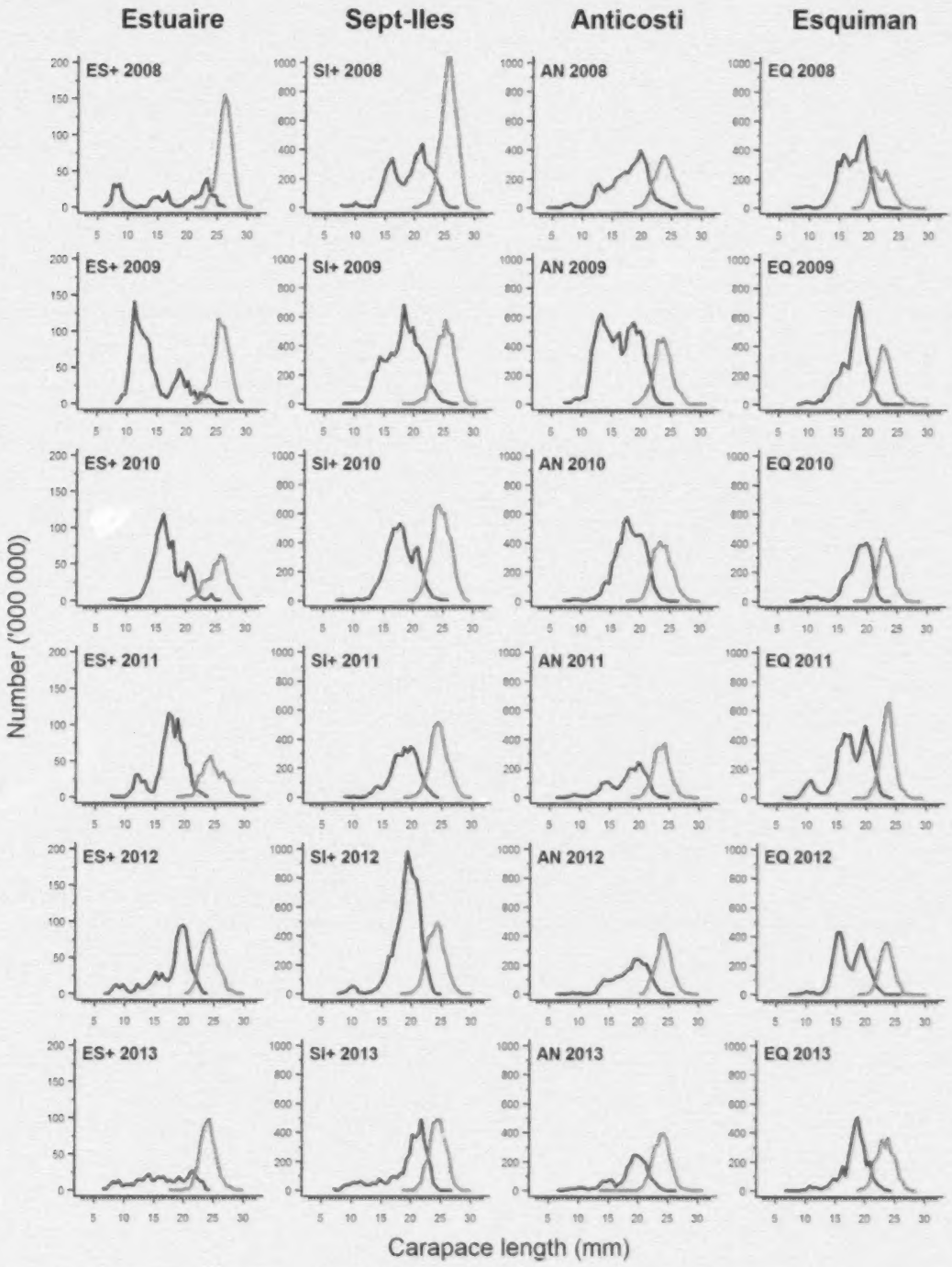

Figure 15. Abundance (in million) by carapace length class (classes of 0.5 mm) by fishing area from 2008 to 2013 for males (in blue) and females (in red). The + placed beside the area shows the results obtained when adding strata in shallow waters (37-183 m) of the estuary.

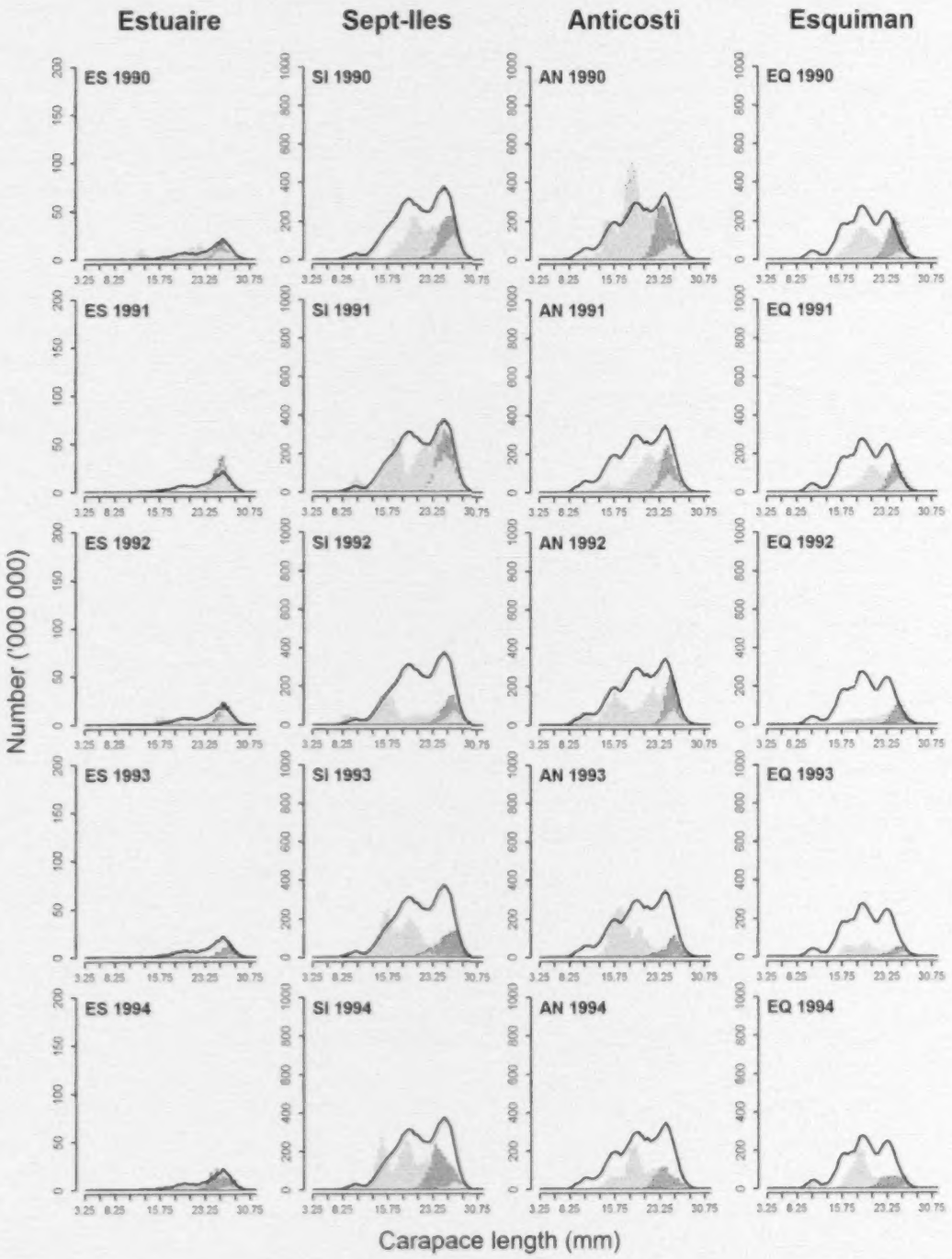

Figure 16. Abundance (in million) by carapace length class (classes of 0.5 mm) by fishing area for males (in blue), primiparous females (in red) and multiparous females (in green). The straight line indicates the average for 1990-2012 or 2008-2012 if a + is placed beside the area. The + placed beside the area shows the results obtained when adding strata in shallow waters (37-183 m) of the estuary.

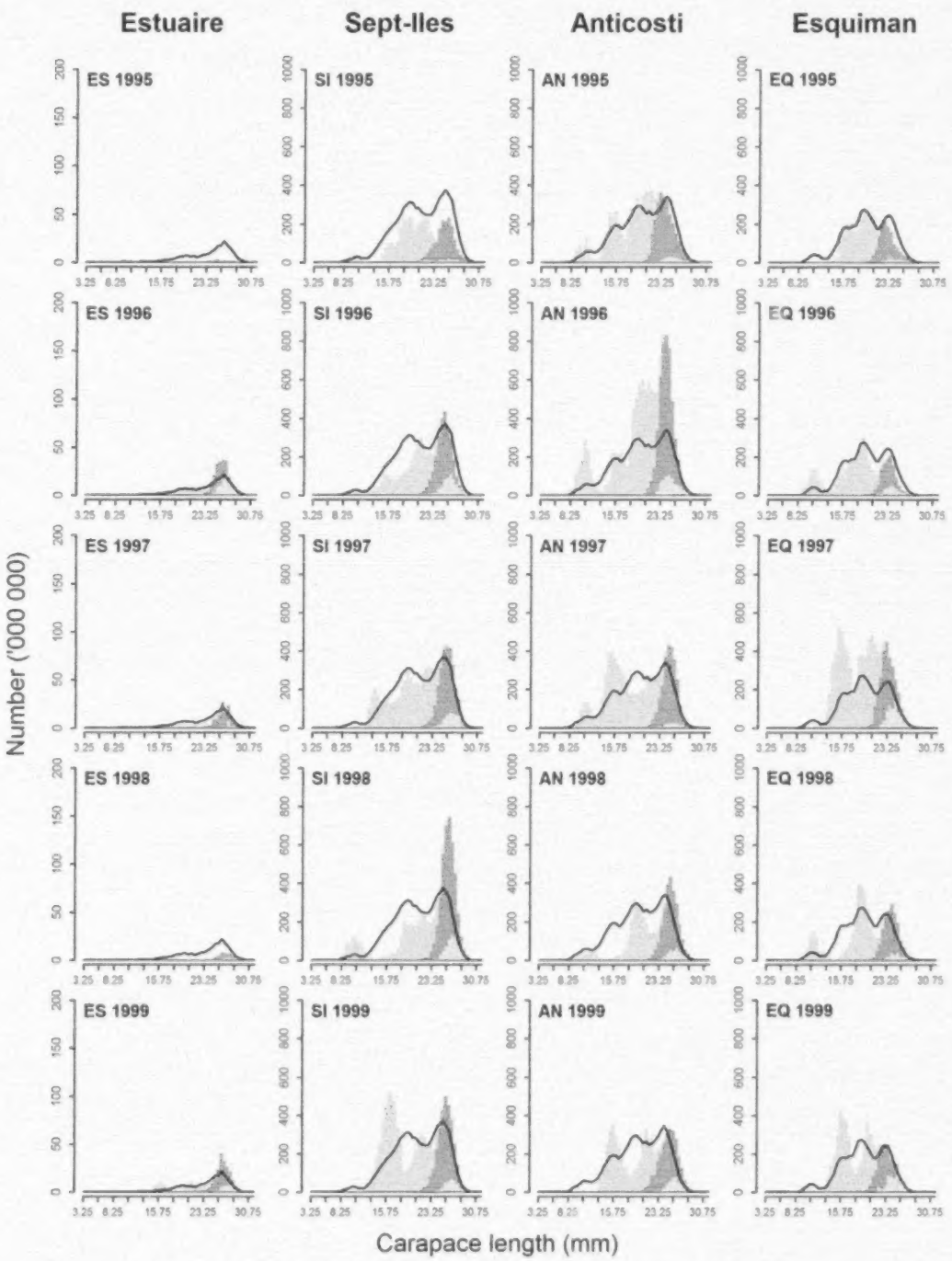

Figure 16. Continued.

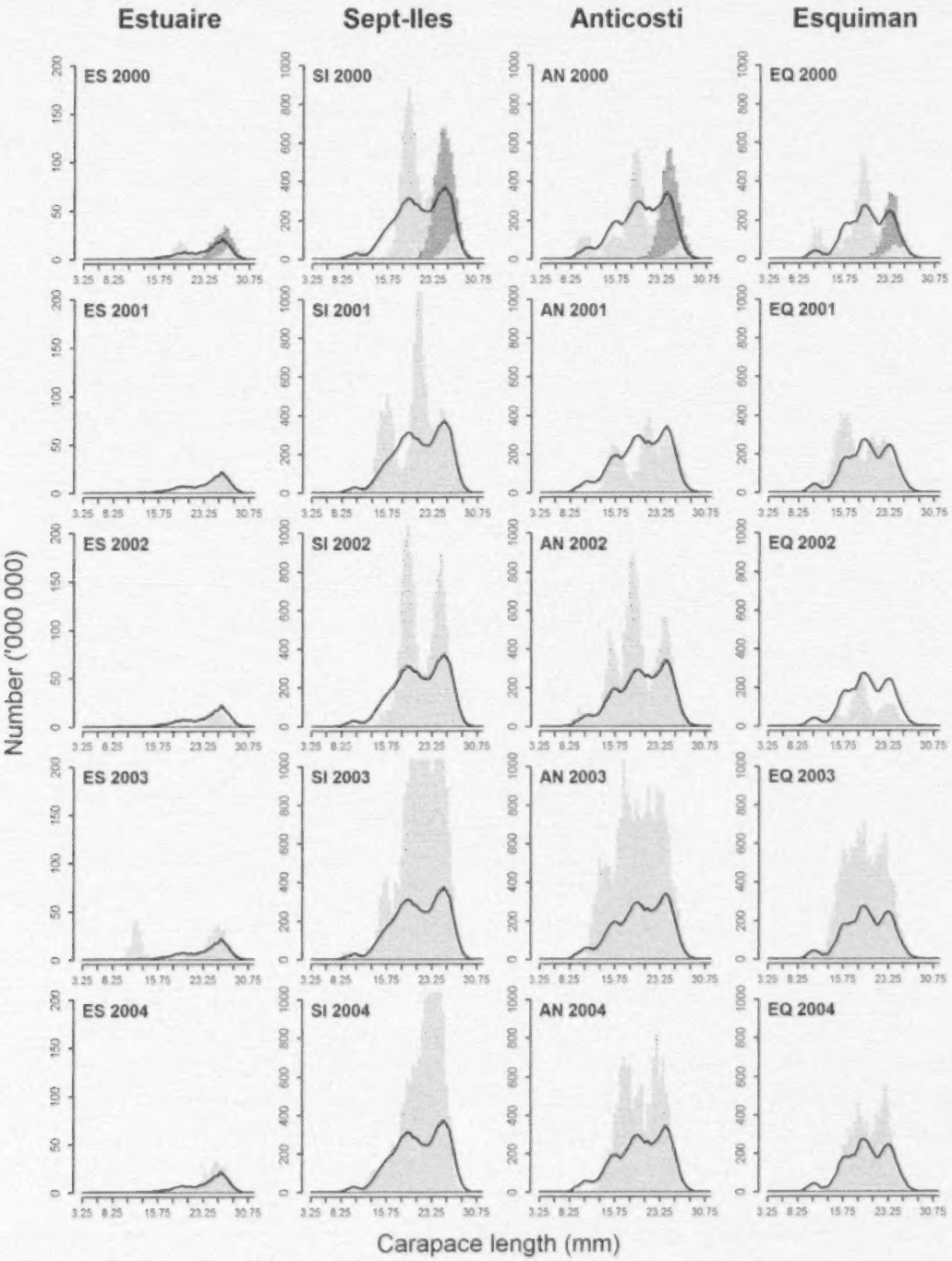

Figure 16. Continued.

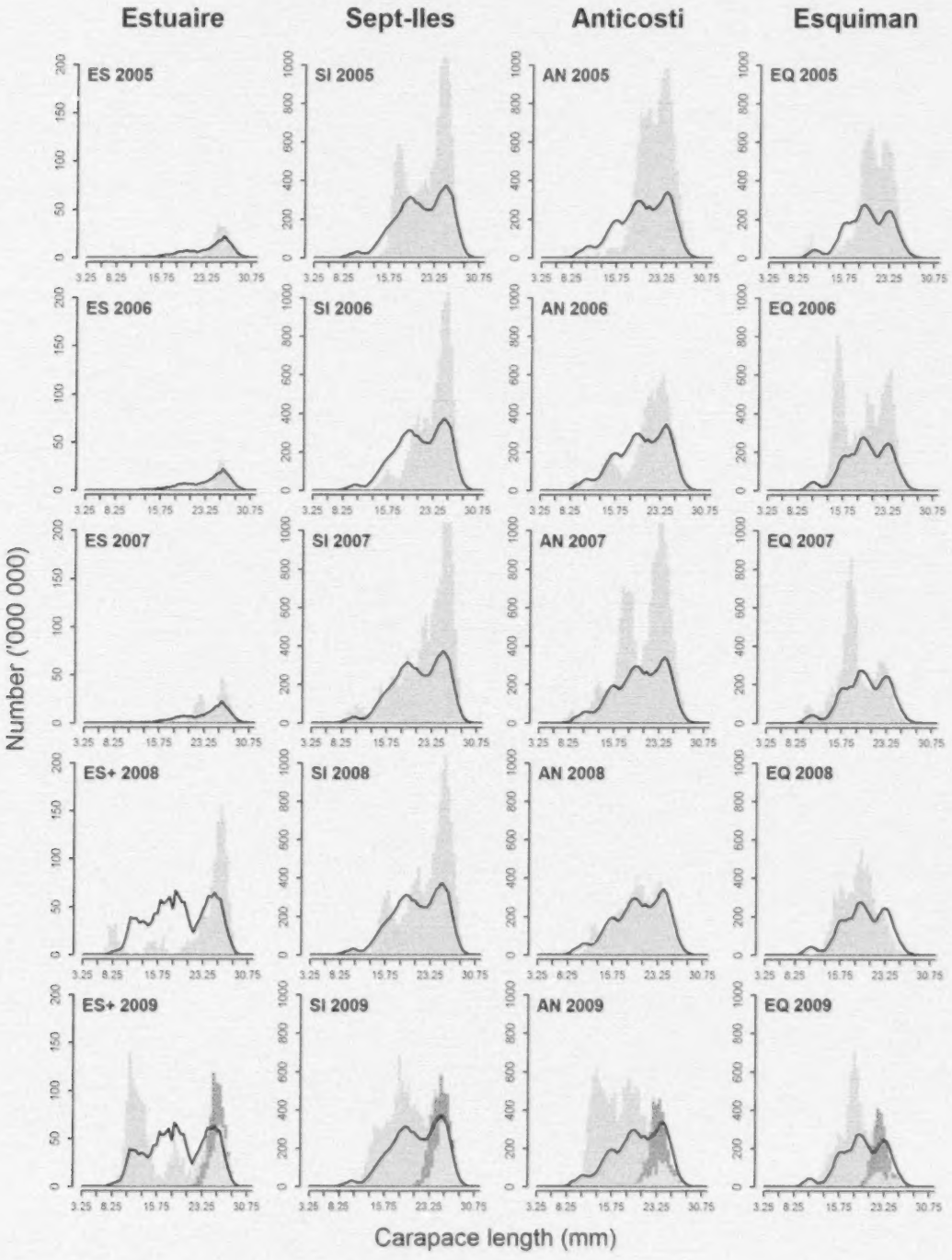

Figure 16. Continued.

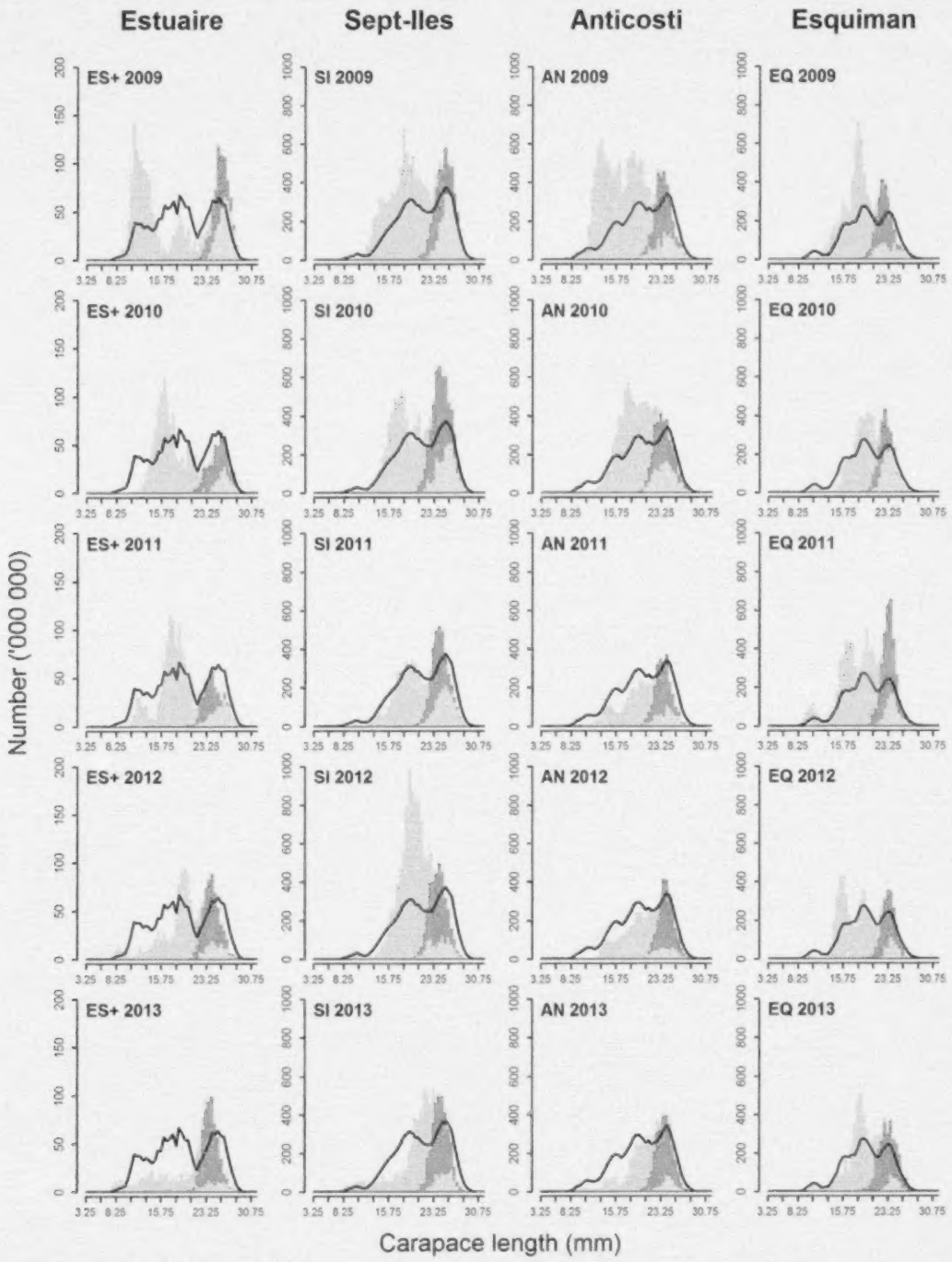

Figure 16. Continued.